A1250-1
8/4/88

AUGUST 1, 1988

CHEMICAL & ENGINEERING

NEWS

FINAL PROGRAM
ACS meeting in Los Angeles
Page 49

FLUORIDATION

Contention won't go away
Page 26

05111790098 9 K AR6631SL 1
CONGRESSIONAL INFO SERV-SRI
4520 EAST WEST HWY SUITE 800
SRI ACQUISITIONS
BETHESDA MD 20814

CHEMICAL & ENGINEERING
NEWS
AUGUST 1, 1988

Volume 66, Number 31
CENEAR 66 (31) 1–156
ISSN 0009-2347

News of the Week

■ **Court cases in Connecticut and Texas are introducing new complexities to the legal battle between Union Carbide and India over settlement of claims from the Bhopal disaster.** **Page 4**

■ **Growing demand for ethylene and its derivatives has set the stage for plant capacity expansions in the chemical industry.** **Page 5**

■ **Ring shape of benzene molecules is visible in scanning tunneling microscope images obtained by IBM scientists.** **Page 5**

■ **The British government is reducing its work on fast breeder nuclear technology.** **Page 5**

■ ***Nature* has denounced research results it published four weeks ago as "not reproducible."** **Page 6**

Business

Although U.S. chemical exports are rising strongly, chemical trade in general seems to be flaunting conventional economic wisdom. **Page 9**

Cheaper electricity and steam for the chemical process industry is being offered by small Philadelphia power company. **Page 11**

Government

Evidence needed to list a chemical as likely carcinogen in HHS annual report is debated again by industry and citizen activist groups. **Page 14**

Modified acid rain proposal calling for national cost-sharing effort is being pushed by Senators. **Page 15**

Science

Powerful new metal-chelating agents that form complexes with the more basic syn lone pairs of carboxylate ions are extraordinarily effective in binding calcium and magnesium ions. **Page 21**

Education

Six national laboratories offer new student program aimed at providing research experience during the academic year. **Page 24**

Books

"Silicon and Silicones" by Eugene G. Rochow relates history of the development of silicone materials, but omits some key data. **Page 43**

Final Program

Program for 196th ACS national meeting in Los Angeles includes listing of technical papers, general events, registration form. **Page 49**

Letters 2
Editor's Page 3

Concentrates

Business 7
Government 12
Science/Technology 19

The Departments

Software Update 25
New Products 138
Newscripts 156

Special Report

Few scientific controversies have generated as much acrimony as the one over fluoridation of water supplies. Many proponents insist that fluoridation's benefits greatly outweigh its risks, whereas many opponents view it as a potentially harmful medication imposed on the public. **Page 26**

Chemical & Engineering News

1155—16th St., N.W., Washington, D.C. 20036

Editor: Michael Heylin
Assistant Managing Editors: David M. Kiefer, James H. Krieger, Janice R. Long, Donald J. Soisson, William J. Storck. **News Editor:** Wilbert C. Lepkowski
Staff Editor: Ernest L. Carpenter
Senior Editors: New York: Earl V. Anderson, Stephen C. Stinson; Chicago: Joseph Haggin, Washington: Doron Dagani, Lois R. Ember, Rebecca L. Rawls, Pamela S. Zurer
Associate Editors: Stuart A. Borman, Mairin B. Brennan, Bette Hileman, Richard J. Seltzer
Service Departments Editor: Dolores Miner
Editing Services: Anne Riesberg (Head), Arlene Goldberg-Gist (Editorial Assistant), Patricia Oates (Administrative Assistant)

News Bureaus: Northeast News Bureau: (201) 906-8300 Marc S. Reisch (Assistant Editor), Rachel Eskenazi (Administrative Assistant). Chicago: (312) 256-4143 Ward Worthy (Head). Houston: (713) 973-8161 Bruce F. Greek (Head). Washington: (202) 872-4495 David J. Hanson (Head). West Coast: (415) 653-3630 Rudy M. Baum (Head). **Foreign Bureau:** London: (01) 540-0414 Dermot A. O'Sullivan (Head), Patricia L. Layman (Associate Editor)
Graphics and Production: Leroy Corcoran (Manager). Alan Kahan (Art Director). Barbara Fryer (Production/Art Director). Linda Mattingly (Staff Artist). Diane Kelly (Costing). **Business Manager:** Arthur Poulos
Circulation Development: Cynthia G. Smith

ADVISORY BOARD: William J. Bailey, Jacqueline K. Barton, Ernest H. Drew, Harry G. Drickamer, A. Nicholas Filippello, Myron Foveaux, Vincent L. Gregory Jr., Adam Heller, John D. Holmfeld, Isabella Karle, Koji Nakanishi, Richard Nicholson, Howard A. Schneiderman, Ellen K. Silbergeld, Howard E. Simmons, Robert M. Simon, William P. Slichter

Published by
AMERICAN CHEMICAL SOCIETY
(202) 872-4600; TDD (202) 872-8733
John K Crum, Executive Director

PUBLISHING BOARD: Ned D. Heindel (*Chairman*); *Board of Directors Chairman:* Ernest L. Eliel; *President:* Gordon L. Nelson; John H. Nelson; Louis D. Quin; Jeanne M. Shreeve; and Barbara G. Wood

© Copyright 1988, American Chemical Society

Subscription & Member Record Service: Send all new and renewal subscriptions with payments to: Controller, ACS, P.O. Box 28597, Central Station, Washington, D.C. 20005. Correspondence and telephone calls for changes of address, claims for missing issues, subscription service, status of records and accounts should be directed to: Manager, Membership & Subscription Services, ACS, P.O. Box 3337, Columbus, Ohio 43210; (614) 421-3776.

For changes of address, include both old and new addresses with ZIP code numbers and mailing label from a recent issue. Allow four weeks for change to become effective. Claims for missing numbers will not be allowed if loss was due to failure of notice of change of address to be received in the time specified; if claim is dated (a) North America: more than 90 days beyond issue date, (b) all other foreign: more than one year beyond issue date; or if the reason given is "missing from files."

Subscription Rates 1988. Printed editions: nonmembers U.S. 1 yr. $49, 2 yr. $83, outside U.S. 1 yr. $75, 2 yr. $135. Air freight rates available on request. Rates above do not apply to nonmember subscribers in Japan, who must enter subscription orders with Maruzen Co. Ltd., 3-10 Nihonbashi 2-chome, Chuo-ku, Tokyo 103, Japan. Tel: (03) 272-7211. Single copies: Current $7.00. Rates for back issues and volumes are available from Microforms & Back Issues Office, ACS, 1155—16th St., N.W., Washington, D.C. 20036. Back and current issues available on microfilm and microfiche. Rates on request from Microform Program, ACS.

Chemical & Engineering News (ISSN 0009-2347) is published weekly except for the last week in December by the American Chemical Society at 1155—16th St., N.W., Washington, D.C. 20036. Second-class postage paid at Washington, D.C., and additional mailing offices. POSTMASTER: Send address changes to Chemical & Engineering News, Membership & Subscription Services, P.O. Box 3337, Columbus, Ohio 43210. ACS assumes no responsibility for the statements and opinions advanced by the contributors to its publications.

Advertising Management
CENTCOM LTD.
(For list of offices see page 155)

LETTERS

CHEMICAL SAFETY

Organolanthanides plus nitrates equals dangerous mix

SIR: A recent article on cerium triscyclopentadienyl [Jacob, K., et al, *Z. Anorg. Allg. Chem.*, **556,** 170 (1988)] made by a process that we announced in 1984 in *Proceedings of the NATO ASI* (Series C, Vol. 155) prompts us to report the following.

When dry ceric ammonium nitrate (CAN) is reacted with sodium cyclopentadienyl (NaCp) under inert conditions, $CeCp_3$ and Na nitrate are produced. Normally the nitrates are filtered off. Recently, however, the solvent was removed without separating the nitrates. A violent explosion occurred when the solid reaction product mixture was heated to 75 °C. Fortunately, the damage was only material since no one was in the vicinity.

$CeCp_3$ is extremely reactive toward traces of oxygen. It blackens and deactivates instantaneously upon exposure. In the absence of atmospheric oxygen and upon heating, the oxophilicity of the element is manifested toward the nitrates in a really loud manner. Under certain conditions, mixed $Ce(NO_3)Cp_2{\cdot}NaNO_3$ complexes are obtained. They decompose with force even when a few milligrams are heated. Since there is no mention of this in Jacob's article, one could assume that these circumstances were not encountered. However, the potential of a dangerous occurrence still exists.

In view of a definite advantage in using nitrates as starting materials for preparative organolanthanide chemistry, those who might be tempted to try this route should take notice of this observation and warning that might not be restricted to cerium.

Peter S. Gradeff
Rhône-Poulenc Inc.

Coal-burning emissions

SIR: J. R. Brown et al. (C&EN, May 23, page 2) comment on the possibility that coal burning may produce significant chlorine and fluorine emissions, presumably as chlorinated and fluorinated hydrocarbons, which may consume stratospheric ozone. They provide a quantitative basis for this inference using the assumptions that "percent levels of fluorine and chlorine are common in coal" and that 0.1% is a "conservative" estimate of fluorine in coal. There is substantial literature which refutes these assumptions. Hodges et al. [*J. Inst. Energy*, **56,** 158 (1983)], in an excellent review of chlorine in coal, show levels as high as 1% for only a few selected U.K. coals. Most commercially important coals have chlorine contents less than about 0.2%, with chlorine contents less than 0.1% being very common. Chlorine contents of 1% are exceedingly uncommon. Moreover, because of the potential detrimental effects of chlorine on boiler hardware, coal users tend to specify low chlorine levels in purchasing coals. Therefore, the chlorine levels in commercially important coals tend to be lower than might be inferred from a compendium of reserve analyses.

Fluorine levels in coal are also significantly lower than the 1% Brown finds common, or his 0.1% conservative estimate. Typical levels in commercially important U.S. coals are 10 to 100 ppm, or one to three orders of magnitude lower.

Finally, the occurrence of the element at any level says nothing about its mode of emission into the environment. In the case of coal combustion, chlorine and fluorine are converted to hydrogen chloride and hydrogen fluoride and not to chlorofluorocarbons. Source apportionment studies such as those by Czuczwa and Hites [*Environ. Sci. Tech.*, **18,** 444 (1984)] indicate that coal combustion is a very minor source of chlorinated hydrocarbons compared with, for example, municipal incineration. Emissions are essentially eliminated at coal-burning units which use alkaline scrubbers for SO_2 control, since these also remove any hydrogen chloride produced by combustion.

There are unanswered questions related to the fate of halogens in coal utilization. However, it is well known that concentrations of halogens in commercially important coals are much lower than stated, that most of the halogens are converted to hydrohalic acids during combustion, and that these are readily captured by scrubbers. The use of statistical inference, based on questionable assumptions, to create the impression of a large potential problem is unwarranted.

F. P. Burke
Director, Applied Research
R. A. Winschel
Group Supervisor, Exploratory
Consolidation Coal Co.
Library, Pa.

U.S. Chemical Exports Rising, But Trade Data Pose Questions

Despite the influence of a weaker dollar, chemical imports grow faster than exports, and export prices grow faster than import prices

Earl V. Anderson,
C&EN Northeast News Bureau

The five-month trade figures recently released by the Bureau of the Census give U.S. chemical companies plenty to cheer about. They also give the industry plenty to ponder.

Through the first five months of the year, U.S. chemical exports totaled $12.9 billion, 22% higher than in the first five months of 1987. That's the cheerful news.

One of the things to ponder, however, is that U.S. chemical imports are growing faster than exports. In the January-to-May period, chemical imports, at $8.3 billion, were 28% ahead of last year's total for the five months.

Conventional wisdom says that this is not supposed to happen. Since 1985, the dollar has depreciated about 50% against foreign currencies, according to some well-regarded yardsticks. Although the dollar has recovered some of its strength this year, it's still much weaker than it was in 1985. And a weaker dollar is supposed to help exports and hurt imports by making exports less expensive and imports more expensive.

On a total trade basis, this is exactly what has happened. U.S. exports have exploded this year. They were up about 30% (in the year's first four months) compared with only about 12% for U.S. imports. But it obviously has not happened in chemical trade.

Chemical trade, in fact, seems to be flaunting conventional economic wisdom. Chemical imports have been rising faster than exports on a constant-dollar basis. Conventional wisdom says that this should not happen.

Chemical import prices have been rising more slowly than chemical export prices. Between March 1987 and March 1988, the Bureau of Labor Statistics' (BLS) chemical export price index rose 18%. The BLS chemical import price index rose only 11%. Conventional wisdom says that this should not happen.

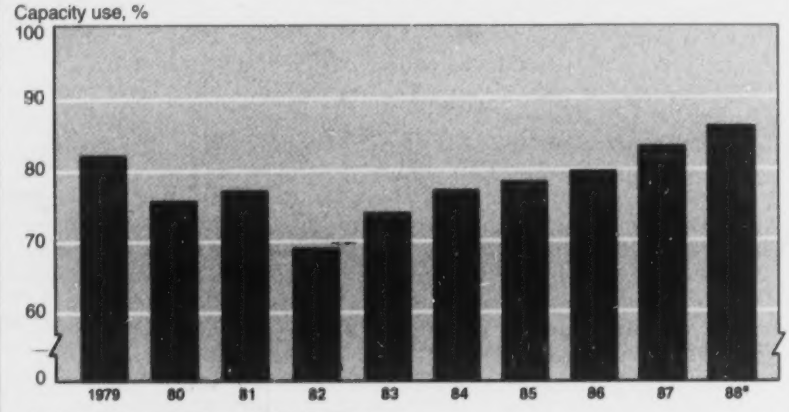
And on a real, or volume basis, chemical imports have grown faster than exports. From March 1987 through March of this year, real volume of chemical exports grew only an estimated 2.3%. Chemical imports grew more than double that, 5.5%. Again, this is contrary to conventional wisdom.

But flying in the face of conventional wisdom may not be so implausible as it may seem for U.S. chemical trade. The relative strength or weakness of the dollar is not the only factor affecting chemical trade, says Vincent J. Kamenicky, director of the office of chemicals and allied products in the Department of Commerce's International Trade Administration. Chemical trade experts in the industry agree. There are several pragmatic explanations, they say, for the seemingly odd behavior of chemical trade.

One analyst says that U.S. chemical export prices have been rising faster than import prices because U.S. exporters are keeping prices high to maximize short-term profits at the expense of long-term market share. Foreign companies, on the other hand, are keeping as tight a lid as they can on prices of products that they ship to the U.S. to maintain or even increase market share.

John S. Schwendiman, manager of strategic studies for Dow Chemical, agrees that "some of this" may be going on. But he suspects that the dichotomy in the behavior of chemical exports and imports may be more of a "mix" problem. That

Chemical industry operating rates are soaring



a Based on first five months. **Source:** Federal Reserve Board

CIRCLE 12 ON READER SERVICE CARD

is, the chemical products that U.S. producers tend to export are commodity chemicals, particularly ethylene derivatives, that have enjoyed huge price increases because supplies are extremely tight. On the other hand, he says, U.S. chemical imports tend to be intermediates that must be processed further. Prices of these products have not risen so much as those of the products that U.S. companies export.

Tight supplies are making it difficult for U.S. chemical companies to increase export volume of some products even if they want to. Polyethylene, ethylene glycol, styrenics, and some vinyls are only a few examples. In some cases, producers are nearing the limits of plant capacity.

The Federal Reserve Board's capacity utilization rate for the chemical industry hit 86.2% in May, the highest it has been since 1973. The board's measure of chemical plant operating rates dropped to 68.5% during the 1982 recession, but has increased steadily ever since. Even at the beginning of last year, the chemical capacity utilization rate was only 80.9%.

And when plant capacity is not the limiting factor, raw material supplies may be. Nowhere is this more apparent than in ethylene. Strong demand and plant outages have combined to make ethylene supplies extremely tight. Allocations now are common and, in some cases, force majeure is in effect. So short are ethylene supplies that Exxon Chemical and Chevron Chemical have teamed up to import the material (C&EN, July 25, page 5).

These conditions make it difficult to increase exports, Schwendiman says. Much of the chemical export market is a "spot market" and, although it is attractive, Dow and other U.S. companies tend to cater to the needs of their long-term, domestic customers first.

Tight markets, around the world as well as in the U.S., are what's making it possible for U.S. companies to keep their export prices high when unit prices, according to theory, should go lower as the dollar goes lower. Says Richard M. Patterson, Dow's government relations manager, "What better time to raise prices than when you're sold out?"

Strong demand and tight supply may explain why chemical export growth is high and chemical export prices are rising faster than import prices. But what about the high growth rates of chemical imports, both on a dollar and a volume basis?

One reason is the surprisingly strong U.S. economy, which tends to attract imports. But George W. Phillips, a consultant specializing in chemical trade affairs, also suspects that a lot of it has to do with the explosive growth of foreign direct investment in the U.S. chemical industry. Phillips recalls that in the 1960s and early 1970s it was U.S. chemical companies that invested heavily in overseas plants, particularly in Europe.

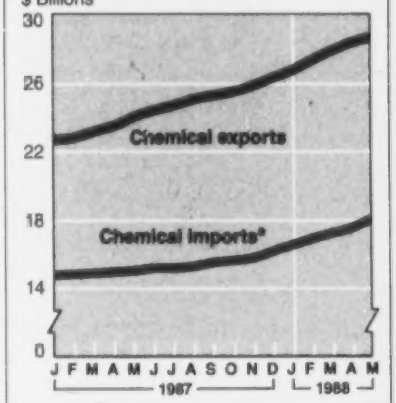
This overseas investment generated what became known as the "pull effect" on U.S. chemical exports. U.S. companies first exported. Then they built plants overseas. Then they found that their exports increased, not only because they often exported raw material for their foreign plants, but because their presence overseas generated a synergistic effect and increased exports of additional products.

Phillips believes that the same thing is happening now, only in reverse. Now, it is the Europeans and others who are investing in U.S. plants. And it is European and other foreign companies whose exports to the U.S. are benefiting.

The cheaper dollar and a huge market have made investing in the U.S. very attractive for foreign chemical companies. Among the foreign giants now with sizable U.S. operations are ICI, Shell, Ciba-Geigy, and the West German Big Three of Hoechst, Bayer, and BASF. Although most of the foreign direct investment in the U.S. is European, Japanese investment is starting to grow. A case in point is Dainippon Ink & Chemicals' recent acquisition of Reichhold.

K. James O'Connor Jr., manager of international trade for the Chemical Manufacturers Association, says that the U.S. chemical industry is the most foreign-owned of any U.S. industry. In 1985, the latest year for which official statistics are available, foreign companies accounted for 27% of the U.S. chemical industry. The all-manufacturing average was 7.6%. The foreign share of the U.S.

Growth quickens for chemical imports, exports



a Customs basis. **Source:** Bureau of the Census

Among chemical exports, plastics show steepest growth

$ Millions	Four months 1988	1987	% change
Organics			
Exports	3,025	2360	28.2%
Imports	2,311	1719	34.4
Inorganics			
Exports	1,172	869	34.9
Imports	1,146	961	19.3
Dyes, tanning & coloring materials			
Exports	231	202	14.4
Imports	381	321	18.7
Medicinals & pharmaceuticals			
Exports	1,206	1068	12.9
Imports	634	440	44.1
Essential oils[a]			
Exports	341	294	16.0
Imports	369	305	21.0
Fertilizer, manufactured			
Exports	738	635	16.2
Imports	456	319	42.9
Plastics & resins			
Exports	2,324	1691	37.4
Imports	767	626	22.5
Other			
Exports	1,244	1032	20.5
Imports	565	471	20.0
TOTAL			
EXPORTS	**10,311**	**8177**	**26.1%**
IMPORTS	**6,688**	**5211**	**28.3%**

Note: Imports are on a customs basis. a Includes essential oils, perfumes, polishing and cleansing materials. **Source:** Bureau of the Census

chemical industry has probably grown by now to well above 30%.

Foreign direct investment in the U.S. chemical industry last year was about $30 billion, topping U.S. overseas chemical investment by $3 billion. On a cumulative basis, the gap between U.S. foreign chemical investment and foreign investment in U.S. chemicals has shrunk dramatically. In 1975, it was $124 billion, versus $28 billion in favor of U.S. chemical investment overseas. Last year, cumulative U.S. chemical investment overseas was $309 billion, but foreign investment in the U.S. chemical industry had grown to $262 billion.

Phillips' theory about the "pull effect" of direct investment on exports and/or imports is no doubt correct. But it is difficult to quantify. Foreign companies keep such data close to their vests. One indication, however, comes from BASF Corp., the wholly owned subsidiary of West Germany's BASF A.G. Last year, BASF Corp. imported $600 million worth of chemicals but exported only half as much ($305 million). Those figures include BASF operations in both the U.S. and Canada. They also are small compared with BASF's total sales of $4.3 billion last year. But despite these limitations, they indicate that foreign investment in U.S. chemicals definitely has a pull effect on imports.

Phillips also believes that U.S. chemical exports may be suffering a "reverse pull effect." For the past few years, several major U.S. chemical companies have been pulling back from Europe. Monsanto, Du Pont, and Union Carbide are among those that have retrenched their European operations. As a result, says Phillips, U.S. chemical exports may not be growing so fast as they would if those overseas investments were still intact.

It appears, then, that U.S. chemical trade is not defying the economic consequences of a weaker dollar, but responding to the economic realities of a unique and major international industry. It also seems certain that the factors influencing U.S. chemical trade, including foreign investment and severe shortages, are not short-term phenomena. □

Power firm offering cheaper cogeneration

O'Brien Energy Systems, a seven-year-old private power company based in Philadelphia, boasts that it can deliver relatively cheap electricity and steam for the chemical process industry.

It can do so, it says, at lower cost than if a company were to provide its own steam or electric requirements, and O'Brien can, in most cases, provide energy more cheaply than the local regulated power company. And it attempts to do so in competition with Catalyst Energy, another independent power company, as well as with subsidiaries of regulated utility firms. Most of the projects O'Brien has contracted for are in areas where electricity rates are high, such as California, Florida, and northeastern states.

But there is a hitch. O'Brien mostly installs cogeneration units with electrical generating capacities of up to 50 MW. To run economically, the power generating unit must be located near the ultimate consumer. And further, the consumer must be in a position to make use of a sustained, balanced source of energy over a period of at least 15 to 30 years, says O'Brien's Bruce Levy, vice president of marketing.

The company currently operates a small cogeneration unit at SmithKline Beckman's research facility in Conshohocken, Pa.; provides methane biogas for steam boiler operations to Atochem Polymers in Birdsboro, Pa.; and has contracts to provide Du Pont's Antioch, Calif., pigments plant with steam from a 46.5 MW cogeneration plant. Another project under contract will result in a 97 MW cogeneration plant that will provide steam for Du Pont's Parlin, N.J., photochemical plant.

About 45 employees are on the payroll of this young company. But its founder, Frank L. O'Brien III, worked for years in the family cogeneration equipment and rental business, which dates back to 1915. Separated from the other family-owned businesses, O'Brien Energy Systems went public in 1986 trading on the American Stock Exchange. Levy characterizes the company as an "energy systems developer," which does the preliminary engineering and overall design for a particular installation. It is the ultimate owner and project manager for each facility, and arranges for financing and construction.

The impetus for the company's formation was the Public Utility Regulation Policy Act passed in 1978. A product of President Carter's drive to foster greater U.S. energy independence, it provided that companies producing power from U.S. sources could compete with and even sell power to a local utility.

The cogeneration plant operating since 1983 at SmithKline's research facility provides the company with 3 MW of power from methane gas recovered on the closed adjacent Montgomery County landfill site. Waste heat from O'Brien's electrical generating unit provides SmithKline with some 13,000 lb per hour of high-pressure steam. "It's not 100% of their needs, but it's a significant amount," Levy says.

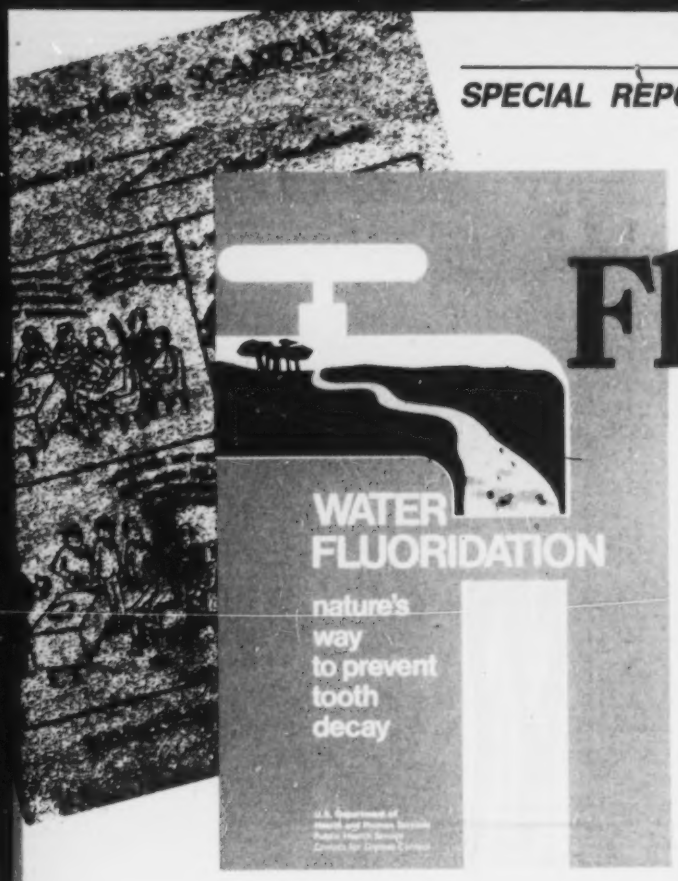
Energy pricing, he says, is "tied either to the local utility rate or the consumer's avoided cost of generating the power. And obviously," he adds, "we have to be offering it to them at a discount. We don't have a rate base as a safety net. We either sell it cheaper or go out of business."

One benefit of recovering biogas at the SmithKline and Atochem sites is in preventing the gas from migrating underground and creating noxious odors or polluting underground sources of water, Levy says. Recovery also offsets the cost of gas extraction at landfills to fulfill Environmental Protection Agency requirements and provides a source of revenue for the landfill operator long after a site has otherwise closed.

At the Atochem site, O'Brien has been collecting biogas from a local landfill since 1985 and supplying it to Atochem, displacing the natural gas the company once bought to fire its boilers, Levy says.

At Du Pont's Parlin site, O'Brien plans to supply steam from a natural gas cogeneration plant, replacing an oil-fired powerhouse. Du Pont's plant manager says that the O'Brien unit will save Du Pont as much as $4 million a year.

Marc Reisch



Fluoridation of Water

Questions about health risks and benefits remain after more than 40 years

Bette Hileman, C&EN Washington

The controversy over fluoridation of water supplies has raged ever since fluoride was first introduced into the drinking water of Grand Rapids, Mich., in 1945. Proponents of fluoridation say it prevents tooth decay and presents absolutely no health risks. Detractors say it causes, or may cause, serious damage to the health of some people. Many also question its effectiveness. For 43 years, there seems to have been no middle ground between the two points of view. "Neither side has given the other one rational moment," explains Jacqueline M. Warren, senior staff attorney with the Natural Resources Defense Council.

U.S. policy makers have had to make other scientific decisions, such as choices about pesticide regulation, that involve the careful balancing of risks and benefits and about which information probably is even more complex. But none has aroused acrimony quite like the fluoridation question. There is hardly any individual interested in the issue who can be classified as neutral, hardly an expert in the field who seems not to be adamantly pro- or antifluoridation. Neither side seems willing to listen to the other. Neither seems able to engage the other in constructive debate.

On the surface this seems surprising. The goal of fluoridation is unarguably worthy. Since U.S. communities began fluoridation in 1945, the prevalence of dental caries has decreased dramatically. The average number of decayed, missing, and filled permanent teeth in U.S. school age children has declined from an estimated seven to about three, according to a national survey released by the National Institute of Dental Research (NIDR) in June.

Why, then, is this issue so polarized?

According to Edward Groth III, an associate technical director of Consumers Union who wrote his Ph.D. thesis in biology on the fluoridation controversy in 1973, pro- and antifluoridationists approach the issue from completely different perspectives. "Proponents see it as a simple public health measure, effective and safe, which they need to 'sell' to the public, almost like a box of soap. Opponents tend to be much more concerned with risks than with benefits, and view fluoridation the same way society views many other 'environmental hazards'—granting that the risks may be small and uncertain, they believe society's attitude should be 'better safe than sorry.' Since any risks fluoridation may present are imposed involuntarily when a water supply is fluoridated, those risks—even if they are tiny or unsubstantiated—tend to provoke a disproportionate amount of outrage."

Indeed, anyone looking closely at the fluoridation debate can discern several separate subdebates, most with more than two distinct positions. Regarding fluoridation's benefits, proponents, such as the American Dental Association (ADA), claim it reduces the incidence of tooth decay 40 to 65% wherever it is used.

Many proponents also insist dogmatically that there is absolutely no evidence that fluoridation has had, or ever could have, harmful effects of any kind on anyone. Some argue that because most natural drinking water contains 0.1 to 0.2 ppm fluoride and nearly all

FACTS FAVOUR FLUORIDATION
WATER IS FOR EVERYBODY. FLUORIDATION ISN'T.
Community Water Fluoridati
The #1 Way to Prevent Dental Decay
FLUORIDIZATION
"The Crime of the Century"
By J. A. Campbell
Research and Development Engineer
641 E. Wardlow Road
Long Beach, California

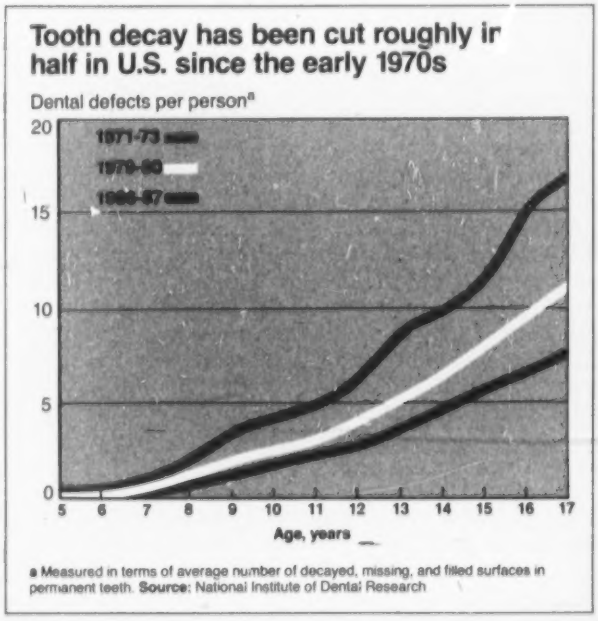
food has traces of fluoride, human beings are adapted to it. For many years, they have also claimed that fluoridation may reduce the incidence and severity of osteoporosis—decreased bone density in old age. Other proponents admit there are a number of recognized potential risks, but they believe there has been enough research of good enough quality to show that these risks are very remote and that the large benefits justify society's taking those risks.

For many opponents of fluoridation, the overriding issue is a moral one of personal rights. These critics oppose fluoridation for ethical reasons. They view it as a form of medication, imposed on the public in violation of individual choice. Given that there are several other ways for people who want fluoride to consume it (for instance, in pills, mouthwashes, toothpaste, fluoridated bottled water), those who place a high value on freedom of choice argue that the state has no right to force them to consume fluoride.

Other opponents of fluoridation claim that fluoridation causes cancer, birth defects, and a large number of other ills. Such claims are frequently made by unscientific activists, who cannot support them with scientific references. But here, too, there are other less extreme opponents who argue that research has not adequately answered most of the critical questions about potential risks. Such critics, many of whom are scientists, cite hundreds of papers published in reputable journals, a collectively large body of evidence of potential hazards that, at a minimum, demands objective assessment. From the start, they also have questioned the benefits of fluoridation, claiming that its effects on tooth decay are nonexistent or greatly exaggerated.

Yet another niche in the debate has lately been filled by environmentalists, who resist being called "antifluoridation" but whose arguments tend to support the opponents. In 1986, the Natural Resources Defense Council (NRDC), one of the U.S.'s pre-eminent environmental advocacy organizations, filed a lawsuit against the Environmental Protection Agency (EPA), seeking to block the agency's proposed relaxation of drinking water standards for fluoride in natural waters. NRDC argued that EPA had inadequately considered the likely effects of fluoride on susceptible subsets of the overall population, had overlooked a great deal of scientific literature that suggested possible harm, and had not adequately evaluated a full range of possible hazards on which the evidence is incomplete or unconvincing. At best, NRDC asserted, EPA had no scientific basis for its action and more research is needed.

In general, environmental advocates believe fluoride should be investigated in the same manner many other environmental pollutants have been studied in recent years. The range of total human intake from air, water, and food must be assessed, they say. The effects on the most susceptible individuals and the levels at which these effects begin to occur should be


Tooth decay has been cut roughly in half in U.S. since the early 1970s
Dental defects per person[a]
20
15
10
5
0
1971-73
1979-80
1986-87
5 6 7 8 9 10 11 12 13 14 15 16 17
Age, years
a Measured in terms of average number of decayed, missing, and filled surfaces in permanent teeth. Source: National Institute of Dental Research

Promoters' style has fueled fluoridation controversy

The style of promotion that fluoridation's proponents have used from the very beginning probably made the issue more controversial than it need have been.

The idea of fluoridating water supplies first arose from studies of dental mottling in areas, such as communities in Texas, where the water supply is fluoridated naturally. In the 1930s, H. Trendley Dean, a dental surgeon at the U.S. Public Health Service, correlated the occurence of mottling or dental fluorosis with the fluoride content of water supplies in 345 U.S. communities. Fluorosis was most common in cities that had the highest concentration of fluoride in their water. He and his colleagues also unexpectedly found a lower incidence of dental caries in areas of endemic dental fluorosis.

Dean concluded that the fluoride content of the drinking water causes a lower rate of dental caries. He also determined that the incidence of mottling was very minor when the fluoride content was 1 ppm or lower but rose linearly at higher concentrations. From this, PHS officials decided in 1943 that 1 ppm was an optimal level at which to artificially fluoridate water supplies in temperate climates. In areas where the fluoride content exceeded 2 ppm, they recommended fluoride be reduced to a level near 1 ppm.

In 1945, PHS initially planned to conduct 10-year studies of artificial fluoridation in two experimental projects, one in New York and one in Michigan. One city in each state would be fluoridated artificially and another would serve as a control. PHS officials intended to complete these projects before deciding whether to recommend fluoridation of drinking water as a general practice for all communities.

However, two public health officers in Wisconsin, Francis A. Bull and John Frisch, quickly became convinced of the effectiveness of fluoridation and launched a nationwide campaign to persuade PHS to endorse it. Also, results from the two projects that leaked out in 1950, after the trials had been going on for five years, revealed a sharp reduction in dental caries in the fluoridated cities. As a result of this disclosure and Bull's and Frisch's campaign, PHS officials endorsed fluoridation on June 1, 1950.

Several deficiencies in research by PHS were subsequently aired at Congressional hearings in 1952 and 1957. There had been almost no careful studies to assess the possible adverse health effects of lifelong consumption of fluor-

determined. Extensive epidemiological studies should be done to see if fluoride is causing cancer or any other more subtle health effects in the general population.

Very little of the research advocated by the environmentalists has ever been done in this country and not much of it has been done anywhere else either. Since the early 1960s, most studies on the long-term effects of chronic exposure to fluoride on human biological systems other than teeth have been carried out in foreign countries.

Current status of fluoridation

Fluoridation of water supplies is largely confined to the English-speaking countries, the Soviet Union, and some Latin American nations. Of the estimated 250 million people in the world who drink artificially fluoridated water (usually fluoridated at 1 ppm), 120 million live in the U.S. (50% of the U.S. population), about 50 million in Brazil (33% of its population), and 40 million in the Soviet Union (15% of its population). Nine percent of the U.K.'s population drinks fluoridated water, two thirds of Australia's and New Zealand's, and 50% of Canada's. However, less than 1% of the population of continental Western Europe has artificially fluoridated water. For 10 years, the Netherlands tried fluoridation and gave it up in 1976 for legal reasons. (Many citizens claimed that the government had no right to add fluoride, which they considered a medicine, to the water supply, and a number of doctors observed strong hypersensitivity reactions to fluoridated water in some people.) It also was tried and then abandoned in a few towns in West Germany for legal and health reasons.

In the U.S., fluoridation is endorsed almost universally by medical and dental associations and by many scientific bodies. The American Medical Association, ADA, the U.S. Public Health Service (PHS), and every Surgeon General since the early 1950s have agreed that water fluoridated at levels of about 1 ppm is a cheap, effective, and perfectly safe way to reduce cavities.

Outside the U.S., a number of scientific groups and individuals have decided fluoridation is not safe. In France, the Chief Council of Public Health rejected fluoridation in 1980 because of doubts about whether it harms human health. The minister for the environment in Denmark recommended in 1977 that fluoridation not be allowed primarily because no adequate studies had been carried out on its long-term effects on human organ systems other than teeth and because not enough studies had been done on the effects of fluoride discharges on freshwater ecosystems. In 1978, the West German Association of Gas & Water Experts rejected fluoridation for legal reasons and because "the so-called optimal fluoride concentration of 1 mg per L is close to the dose at which long-term damage [to the human body] is to be expected."

The battle lines between pro- and antifluoridationists in the U.S. used to be very clear, with the medical and dental establishment and a great many public health officials and scientists on one side and a number of other scientists, private citizens, and members of extreme right wing groups (such as the John Birch Society and the Ku Klux Klan, who claimed fluoridation was a communist plot) on the other. Most of those who spoke out against fluoridation were, according to profluoridationists, either members of one of these

idated water. Aside from their dental health, the medical condition of residents of naturally fluoridated areas had been examined superficially, at best. In one of the fluoridation trials, research plans included a study of adverse effects of artificial fluoridation on children, but none on adults. No studies focused on malnourished children and infants, despite a warning in 1952 by Maury Massler, professor of pedodontics at the University of Illinois College of Dentistry, that "low levels of fluoride ingestion which are generally considered to be safe for the general population may not be safe for malnourished infants and children, because of disturbances in calcium metabolism."

Neither PHS nor anyone else had investigated potential carcinogenic effects, effects on pregnant women, or effects on people with chronic kidney impairment or other chronic diseases. Even in the early 1950s, enough was known of fluoride's toxicity profile to identify these as important topics to investigate.

From the beginning, the movement to fluoridate water was conducted more like a political campaign than a scientific enterprise. At a meeting of state dental directors with PHS officials in June 1951, Bull recommended tactics for promoting fluoridation. "If it is a fact that some individuals are against fluoridation, you just have to knock their objections down. The question of toxicity is on the same order. Lay off it altogether. Just pass it over. 'We know there is absolutely no effect other than reducing tooth decay,' you say, and go on. If it becomes an issue, then you will have to take it over, but don't bring it up yourself."

"The minute doubt is created in the minds of the public, any public health program is doomed to failure," Bull later wrote in the *Journal of the American Dental Association*.

The political role of dentists has been emphasized throughout the history of fluoridation. In 1970, even after 25 years of fluoridation, John W. Knutson, then professor at the University of California Medical Center, advised dentists that when they discussed fluoridation with the public, they must realize that "they are propagandizing, not simply educating." This attitude, widely shared by political proponents, led early advocates to treat fluoridation campaigns as debates to be won with dogmatic assertions and attacks on the credibility of the opposition. To promoters, the debate has never been seen as a scientific search for truth.

As a result, profluoridationists prepare booklets for the public that contain highly biased information. If scientific studies are cited, only those that support their side of the argument are mentioned. Those opposed to fluoridation counter with equally biased propaganda.

radical groups or irrational, fanatic, unscientific, and fraudulent, even if they had legitimate scientific credentials.

Now, however, the lines are not so clearly drawn. Zev Remba, the Washington Bureau editor of *AGD Impact*, the publication of the Academy of General Dentistry (a group of 28,000 dentists dedicated to promoting the continuing education of general practitioners), described the situation in an editorial last year: "Today ... the antifluoridation movement has found supporters on the left as well as the right, particularly among groups dedicated to safeguarding the environment. And as the base of support broadens, community fluoridation appears to be losing ground. In about 60% of 2000 referenda held in the U.S. since 1950, fluoridation has been voted down. A 1985 poll by the American Dental Association found that 36% of the 255 [planned or existing] fluoridation programs surveyed had been cancelled," primarily because they were rejected in referenda.

Last year, the Commissioner for the Department of Health in New York State, David Axelrod, decided to turn the department's emphasis away from fluoridation of water supplies and toward the use of topical sealants and fluoride rinses for school children. The department is still in favor of fluoridating water supplies, but is no longer funding it.

Even now fluoridation remains an issue in many cities across the U.S. Since 1983, referenda have been held on the question in well over 60 communities. In more than half of these, the majority of the people voted against fluoridation. Some referenda are held in cities without fluoridation in order to decide whether to initiate it. Others are called by opponents of fluoridation in cities where it already exists in order to terminate it. ADA and NIDR carry on a continuous campaign to persuade state legislatures to pass laws making fluoridation mandatory in all communities. So far only eight states have passed such laws, but dozens of proposed similar laws have been defeated.

Fluoridation is becoming more of an issue in developing nations as their tooth decay rates rise with the increasing use of sugar and processed food. Countries such as Brazil are now deciding whether to expand fluoridation or initiate it. In May, an international conference was held in Porto Alegre, Brazil, to assess the benefits and risks of fluoridation and help the authorities evaluate the question.

If more diverse interest groups are increasingly skeptical of fluoridation, what are the reasons? Is fluoridation just as effective as it appeared to be in the past? Have scientists uncovered new evidence of real health risks?

Benefits: a changing assessment

Originally, it was thought that the fluoride ion prevented tooth decay solely by being incorporated in tooth enamel as the teeth formed in childhood. Fluoride ingested in water or food is absorbed into the bloodstream. Part of it is excreted and the remainder is deposited in the bones and teeth. The proportion of fluoroapatite in the hydroxyapatite of developing tooth enamel is then increased:

$$Ca_{10}(PO_4)_6(OH)_2 + 2F^- \rightarrow Ca_{10}(PO_4)_6F_2 + 2OH^-$$

Fluoroapatite is less easily dissolved by mouth acids than hydroxyapatite and therefore more resistant to decay.

But today dental researchers believe two other mechanisms are just as important or more so. A number of factors, including fluoride ion, influence a constant exchange of ions across tooth surfaces. Bacteria in the mouth convert sugar to acids, which cause demineralization of tooth surfaces. Demineralization and remineralization take place constantly on the surface. When the pH of the surface drops, calcium and phosphate ions pass from the enamel into the plaque, but if the pH becomes neutral, these ions may redeposit themselves into the enamel. Fluoride ions in the plaque inhibit the bacterial conversion of sugar to acids and thereby help maintain higher pH levels, allowing remineralization to occur. Therefore, the fluoride ions in saliva and plaque may be just as important in preventing tooth decay as the ions in blood—and perhaps just as easily provided by toothpaste as water.

A third mechanism by which fluoride may prevent decay involves incorporation of fluoride into the remineralizing enamel surface, making it more resistant to decay.

For many years, most dentists believed that fluoridation of water supplies reduced tooth decay about 50 to 65%. These figures were based primarily on four studies during the early years of fluoridation: in Grand Rapids, Mich.; Newburgh, N.Y.; Evanston, Ill.; and Brantford, Ont. But a great deal of evidence indicates that water fluoridation reduces dental caries much less. In fact, some research suggests little or no reduction at all.

Alan S. Gray, former director of the Division of Dental Health Services for the British Columbia Ministry of Health, finds, for example, that the average number of decayed, missing, and filled permanent teeth in British Columbia, where only 11% of the population uses fluoridated water, is lower than in parts of Canada where 40 to 70% of the people drink fluoridated water. School districts in the province with the highest percentage of children with no tooth decay are totally unfluoridated. These differences could, of course, be caused by factors other than fluoridation.

Tooth decay is a complicated process, influenced by many factors, including diet, oral hygiene, dental care, genetic predisposition, geochemical factors, and possibly other trace elements, such as strontium, as well as fluoride in the water supply. Additional factors that may affect decay rates are the use of fluoridated toothpastes or topical rinses and the presence of fluorides in foods. Most people whose diet includes little sugar and few processed foods have very low rates of tooth decay. In those few developing countries in which only small amounts of sucrose and refined foods are eaten, decay rates are often lower than in the developed nations. And if other factors are equal, districts in the developed world where the socioeconomic status is higher generally have less decay.

Therefore, comparisons between fluoridated and unfluoridated districts that don't adequately take such factors into account can be readily confounded. None of the early epidemiological studies controlled very well for most nonfluoride variables, so many scientists today have come to regard them as only part of the evidence one must consider to assess the size of fluoridation's benefits.

One recent development that bears on the question is the widespread observation that tooth decay rates in the U.S., Canada, New Zealand, Australia, and in all countries of Western Europe have declined greatly during the past 40 years. Mark Diesendorf, an applied mathematician and health researcher in the Human Sciences Program at Australian National University and an expert in research design, has found, by comparing results from about 24 studies of unfluoridated districts in eight countries, that reductions in dental caries are just as great in nonfluoridated as in fluoridated areas. In Queensland, which is primarily unfluoridated, the rate of tooth decay is as low as it is in the fluoridated districts of Australia.

Diesendorf concludes from such data that fluoridation of water supplies may not be nearly so important in preventing tooth decay as many authorities believe. Some of the decline in dental caries in unfluoridated areas might be explained by the introduction of fluoride toothpaste, tablets, and mouthrinses,

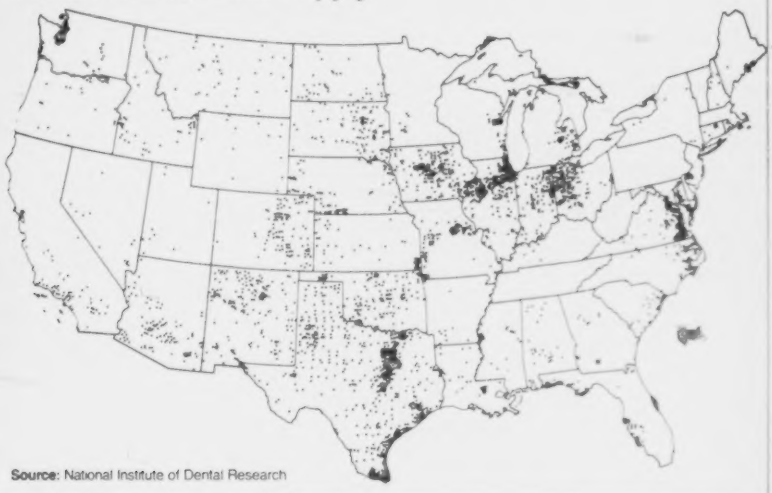
Most major developed countries do not fluoridate their water supplies

Country	Population (millions)	Percent of population drinking artificially fluoridated water
Albania	3.1	0%
Australia	16.1	66
Austria	7.6	0
Belgium[a]	9.9	0
Bulgaria	9.0	0
Canada	25.9	50
Czechoslovakia	15.6	20
Denmark	5.1	0
East Germany	16.6	9
Finland[b]	4.8	1.5
France	55.6	0
Greece	10.0	0
Hungary	10.6	0
Ireland	3.5	50
Italy	57.4	0
Japan	122.0	0
Luxembourg	0.4	0
Netherlands[c]	14.6	0
New Zealand	3.3	66
Norway	4.2	0
Poland	37.7	4
Portugal[a]	10.3	0
Romania	22.9	0
Spain	39.0	Less than 1%
Sweden	8.4	0
Switzerland	6.6	4
U.K.	56.8	9
U.S.	243.8	50
U.S.S.R.	284.0	15
West Germany[d]	61.0	0
Yugoslavia	23.4	0

a One experimental treatment plant now discontinued. b One small experimental treatment plant. c Discontinued in 1976 after 23 years of experiments. d Discontinued in 1978 after 18 years of experiments.

H. Trendley Dean's studies during 1930s and 1940s established relation of fluoride level in drinking water with tooth decay and dental fluorosis

Many U.S. communities have 0.7 ppm or more natural fluoride in their water supply



Source: National Institute of Dental Research

he says, but decay rates began to fall in many of the nonfluoridated regions long before these were available. He believes that changes in nutrition, oral hygiene, and possibly the immune status of the population may explain part of the decline.

A number of researchers in the U.S. have reported similar findings. Stanley B. Heifetz and coworkers at NIDR note in the April issue of the *Journal of the American Dental Association* that "the current reported decline in caries in the U.S. and other Western industrialized countries has been observed in both fluoridated and nonfluoridated communities, with percentage reductions in each community apparently about the same."

Robert L. Glass of Forsyth Dental Center, Boston, noted that in 1965, after more than 20 years of fluoridation, counts of decayed, missing, and filled permanent teeth for Grand Rapids, Mich., and Newburgh, N.Y., were only minimally different from the average for the entire U.S., which then was about 33% fluoridated. Because he had expected nonfluoridated areas to have higher decay rates than fluoridated ones, and to therefore raise the average for the entire U.S., he concluded that the U.S. average had not been determined correctly. It is also plausible, however, that the effects of fluoridation had been overstated, or perhaps that Grand Rapids and Newburgh had exceptionally high levels of decay before fluoridation began.

Other recent reports indicate that fluoridated areas have lower decay rates than unfluoridated areas, but by much less than the alleged 50 to 60% difference. A 1983 study of tooth decay in 10 cities by the Robert Wood Johnson Foundation and Rand Corp. found that fluoridated cities have roughly one third less decay, which means that average 12-year-olds in fluoridated cities have about 0.6 fewer cavities than those in nonfluoridated cities. Gray points out that decay reductions of even 33% taking place today, when average base decay rates are at such a historically low level, do not mean as much as they did in the past.

Research conducted in the 1930s and 1940s in the U.S. showed that the incidence of dental caries was reduced most effectively where the natural fluoride level of the water supply was 1 ppm or above. But five studies in India, Sweden, Japan, the U.S., and New Zealand do not support this trend. In the Japanese study, for example, children in an area with 0.3 to 0.4 ppm fluoride in the water have the lowest decay rates; above and below this range, caries prevalence increases rapidly. These results contradict a central tenet of the fluoridation theory—that the ideal fluoride level, producing low decay rates with minimal damage to the teeth, is about 1 ppm.

At NIDR, officials are reassessing the decay reductions that can be attributed to fluoridated water. Herschel S. Horowitz, formerly chief of the clinical trials section of the caries prevention and research program, says that recent studies suggest that reductions are not so large as the 50 to 60% indicated by early studies. NIDR scientists are trying to determine what they call a "new baseline." Whatever the ultimate result, a consensus seems to have emerged that the promise of "two thirds less tooth decay" with fluoridation is no longer realistic, if indeed it ever was.

In a similar vein, the economic benefits of fluoridation appear to have been exaggerated. NIDR states that every dollar spent on fluoridation, which costs only 20 to 50 cents per person per year, reduces dental costs $50. NIDR assumes that fluoridation reduces cavities some fixed percent, such as 40%, and then multiplies the total number of cavities theoretically prevented by the average cost of filling one cavity. But when the actual costs of dental care delivered in similar cities are compared, residents of fluoridated cities seem to reap no economic benefit from fluoridation. In one study, reported in a February 1972 article

in the *Journal of the American Dental Association*, the cost of dental care in five unfluoridated cities in Illinois was compared with costs in five similar cities with naturally fluoridated water. Even though dentists' fees and the nature of treatments in the two groups of cities did not differ significantly, the cost per patient and the average number of visits to the dentist per year were greater in the fluoridated communities.

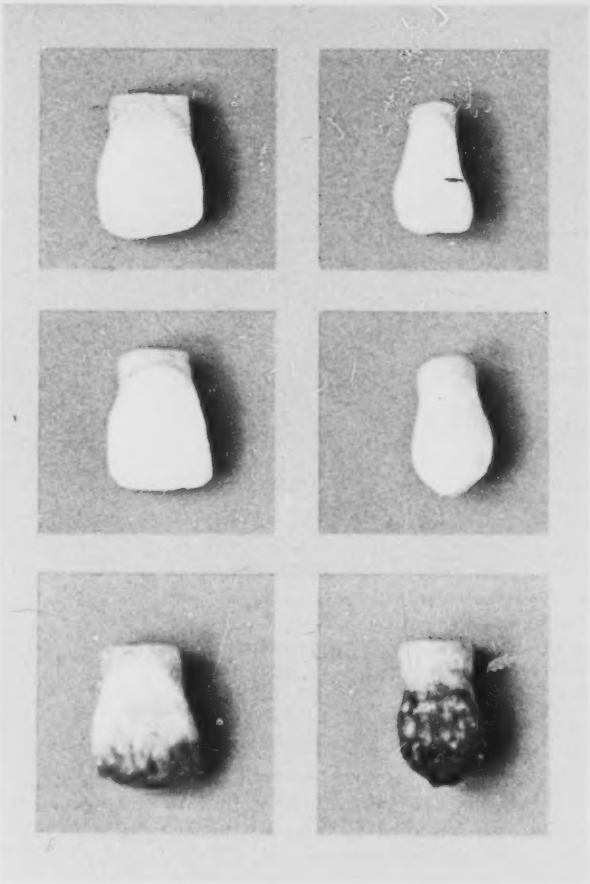
Proponents also are trying to show that fluoride can be used to alleviate the symptoms of osteoporosis, and therefore that people living in fluoridated areas may be helped by the excess fluoride they are accumulating in their bones. Because excess fluoride produces osteosclerosis (denser bones), patients in numerous clinical trials have been given and are still being given large doses of fluoride (60 to 80 mg per day) as treatment for osteoporosis. So far this method has produced no definitive beneficial results. In a 1987 review of fluoride therapy for osteoporosis, Louis V. Avioli, professor at the Washington University School of Medicine, concludes: "Sodium fluoride therapy is accompanied by so many medical complications and side effects that it is hardly worth exploring in depth as a therapeutic mode for postmenopausal osteoporosis, since it fails to decrease the propensity toward hip fractures and increases the incidence of stress fractures in the extremities." FDA has not approved the use of fluoride for osteoporosis.

Health risks: more questions than answers

The physiological effects of fluoride on the human body range from those about which there is a great deal of scientific information to those that are less certain, but about which there is some credible evidence, to those that are almost purely speculative. Even the effects for which there is good information are controversial. Some scientists define them as health effects, but others consider them as merely cosmetic or conditions without negative implications for health.

More than any other area of fluoride research, scientific debate over potential health hazards has been polarized by the political controversy over fluoridation. Does a study show adverse effects? Is certain evidence relevant to an assessment of the safety of fluoridation at 1 ppm? The answers experts give differ, depending on whether the experts favor or oppose fluoridation. The political schism over the measure has dominated scientific discourse on the topic, almost totally blocking consensus over what the evidence of adverse effects means—or in some cases, even over whether such evidence exists.

The effects of fluoridation that have been studied the most are dental fluorosis (mottling of teeth), skeletal fluorosis, kidney disease, hypersensitivity reactions, enzyme effects, genetic mutations, birth defects, and cancer. The information about dental fluorosis is clearest and least controversial. Knowledge of skeletal fluorosis is extensive, but not at all complete. The information about fluoride and kidneys is partly established and, in part, almost purely speculative owing to a lack of research. Hypersensitivity reactions have been studied thoroughly by only a few investigators and many important issues remain unresolved. Birth defects and cancer have been much discussed, but evidence in these areas is the most uncertain.



Copyright Ingolf J. Møller, Copenhagen

Fluoride in drinking water may affect teeth to various degrees during the years of tooth formation, depending on the degree of exposure and individual sensitivity. Compared with a normal tooth (top row, left), a tooth with questionable fluorosis (top row, right) shows no clear evidence of change, for instance, and one with very mild fluorosis (middle row, left) only has small white flecks. However, a tooth with mild fluorosis (middle row, right) has chalky white areas; moderate fluorosis causes yellow or brown mottling (bottom row, left); and a tooth with severe fluorosis (bottom row, right) is heavily stained, pitted, brittle, and susceptible to fracture

Though profluoridation statements almost always claim that all risks have been fully investigated and found to be groundless, in fact a number of important unanswered questions remain about each of these health risk areas. The 1977 National Academy of Sciences report "Drinking Water and Health" recommends research in 11 different areas. Even though more than a decade has passed, research in only three health effects areas, dental fluorosis, cancer, and birth defects, has been funded by the federal agencies responsible for research on fluoride (PHS and EPA).

The fluoride ion is unusual among trace elements in water or food because the same range of human exposure to fluoride ion that can produce beneficial physiological effects can also produce harmful effects. For most trace elements, such as chromium, manga-

nese, and zinc, beneficial and harmful ranges of exposure differ greatly.

In 1962, PHS set fluoride levels of 0.7 to 1.2 ppm in drinking water as the ideal range to prevent dental caries with minimal dental fluorosis. The lower level was suggested for hot climates and progressively higher levels were prescribed for cooler regions, because average water consumption varies with temperature. Natural fluoride levels exceeding twice the ideal for the climate, PHS said, constituted grounds for rejection of the water supply, but it had no power to force communities to remove excess fluoride.

In 1975, EPA took over PHS's responsibility for regulating contaminants in drinking water and, in 1986, relaxed the maximum contaminant level to 4 ppm for all climates. Communities that add fluoride to drinking water still do so according to the old PHS formula. But communities with naturally fluoridated water are not required to remove fluoride unless the level exceeds 4 ppm. Some of the potential adverse health effects, however, may occur at levels of about 1 ppm and above and are both more pronounced and more widespread at levels near 4 ppm.

In humans, 98% of the fluoride ingested in water is absorbed into the blood from the gastrointestinal tract. The fluoride diffuses to the body's cellular tissues and most of it is deposited in the bones and teeth or excreted by the kidneys. The aorta is the only other tissue that normally accumulates significant amounts of fluoride, mainly in calcified deposits. The amount stored in bones and teeth varies depending on the age of the subject. According to NIDR's Heifetz and Horowitz, in children more than 50% of an ingested dose of fluoride may be deposited in bone, but in adults only about 10% is stored there. As with teeth, fluoride is deposited in bone by simple ionic exchange with the hydroxyl groups of hydroxyapatite. It also is removed from bone, though at a slower rate than it is deposited. If the intake remains constant, the level of fluoride in the bones increases linearly with age.

The most obvious and common effect of fluoride on humans is dental fluorosis. This occurs only if children drink fluoridated water, receive fluoride supplements, or ingest significant fluoride from other sources (like toothpaste) during the years of tooth formation. In excessive amounts, fluoride interferes with the normal function of the enamel-producing cells in the jaw, called ameloblasts, in laying down amelogen matrix and in the mineralization of this enamel matrix. (Amelogen is a collagenlike material that forms the structural foundation and framework upon which calcium and phosphate are deposited, giving rise to tooth enamel.)

The late H. Trendley Dean, a dental surgeon at PHS, defined five degrees of dental fluorosis: questionable, very mild, mild, moderate, and severe. In the questionable form, evidence of fluorosis is uncertain; in the very mild form, teeth have small white specks; in the mild form, teeth have chalky white areas; in the moderate form, they may have yellow

Some studies indicate that dental fluorosis is increasing

Scientists disagree over whether the incidence of dental fluorosis is increasing in the U.S. as more children drink fluoridated water and use fluoride supplements, toothpaste, mouth rinses, and topical applications during the years of tooth formation.

Dennis Leverett, chairman of the department of community dentistry at the Eastman Dental Center in Rochester, N.Y., claims that the prevalence of dental fluorosis today in communities with fluoridated water is twice the level that H. Trendley Dean, a dental surgeon in the Public Health Service, reported in 1942 from his studies of communities with the same level of natural fluoride in their water supply. Leverett fears that if additional studies substantiate his findings, fluoride levels in supplements, toothpastes (most of which contain 1000 ppm fluoride), and water may need to be reassessed. He reasons that the increase in fluorosis may result from the increased use of fluoridated toothpastes, supplements, and perhaps from higher levels of fluoride in the food chain. Today, nearly all bottled drinks and canned foods in the U.S. are processed with fluoridated water. Should further studies confirm Leverett's conclusion, it would validate a warning that has been sounded by scientific critics of fluoridation for at least 25 years.

In contrast, William S. Driscoll, acting chief of the disease prevention and health promotion branch at the National Institute of Dental Research (NIDR), and his coworkers report that surveys in 1980 "suggest that no important changes in the prevalence and severity of fluorosis have taken place" since Dean's studies. However, Driscoll did find eight children with either moderate or severe fluorosis in a community with a fluoride level of 1 ppm. In the 1930s, Dean generally found no children with advanced forms of fluorosis in the many towns he surveyed with 1 ppm natural fluoride in the water supply.

In 1985, Stanley B. Heifetz, Driscoll, and their coworkers at NIDR surveyed the same areas in Illinois they had surveyed in 1980. The prevalence of fluorosis in eight- to 10-year-olds changed little between 1980 and 1985. But among 13- to 15-year-olds, the researchers note a greater prevalence and severity of fluorosis in 1985 than in 1980. In 1985, only 71% of tooth surfaces were fluorosis-free in a community with 1 ppm fluoride, compared with 89% in 1980. In a community with 4 ppm fluoride, fluorosis had become so prevalent that 93% of the visible tooth surfaces showed some signs of the condition, compared with 76% in 1980.

Several studies indicate, therefore, that the prevalence of dental fluorosis is rising, particularly at fluoride levels of 1 ppm, a level at which objectionable fluorosis was extremely rare in the 1930s. But the populations studied are so limited that it is difficult to determine how much fluorosis is increasing.

and brown stains; in the severe form, depending on the amount of fluoride ingested, they are pitted, brittle, and susceptible to fracture. Severe fluorosis not only produces unattractive teeth but also may increase the risk of tooth loss because it destroys parts of the protective enamel.

According to a recent study conducted by NIDR in areas with different concentrations of naturally occurring fluoride in their water supplies, 2% of the children developed moderate or severe fluorosis and about 12% developed very mild and mild fluorosis at 1 ppm—the level of fluoride that NIDR considers ideal. But at 4 ppm, the maximum fluoride level EPA now allows in the U.S., 7% had moderate and 23% severe dental fluorosis (approximately the same total fraction of objectionable fluorosis Dean noted in the 1930s in 4-ppm areas). Since this study was very limited, the percents of fluorosis may not be representative of the country as a whole.

But if the fraction of children subject to moderate and severe dental fluorosis is anywhere near 1 or 2% in most areas with 1 ppm fluoride, a great many children are at risk of developing disfiguring degrees of fluorosis. And, of course, a large fraction of children in the 4-ppm areas would develop noticeable fluorosis. To avoid dental fluorosis, "children under five years of age should drink water diluted with a fluoride-free source in communities with 4 ppm fluoride," NIDR's Horowitz says.

There seems to be little controversy over what levels of fluoride in water cause moderate and severe dental fluorosis. Scientists disagree, however, about whether moderate to severe dental fluorosis is a health effect. This may seem like an academic issue, but under the Safe Drinking Water Act, EPA is required to set recommended maximum contaminant levels (RMCLs) that will prevent known or anticipated adverse health effects with an adequate margin of safety and to set the maximum contaminant levels as close to the RMCLs as is feasible. (The RMCLs are unenforceable goals; the maximum contaminant levels are enforceable standards.) A special committee convened by the Surgeon General in 1983 to guide EPA in setting its fluoride standard wrote in the first draft of its report that moderate to severe dental fluorosis per se is a health effect. The second draft, presented to the Surgeon General in September 1983, said that moderate to severe dental fluorosis is only a cosmetic effect—the position long held by political advocates of fluoridation. This rationale allowed EPA to ignore dental fluorosis in setting the RMCL for fluoride.

Municipal treatment plant in Gila Bend, Ariz., uses selective adsorption with activated alumina to reduce excess fluoride level in drinking water

Skeletal fluorosis

One solidly established concept in environmental health is that the effects of toxic agents fall on a continuum of biological change, ranging from undetectable effects at the lowest levels of exposure to severe health damage at very high doses. As exposure to an agent increases, the first detectable effect may be a subtle biochemical change, such as a decrease in the activity of an enzyme. At somewhat higher doses, measurable changes in some physiological functions may occur, but these often are not linked to clear symptoms or adverse effects, and may not be harmful. But as dosage increases, adverse effects begin to appear—at first mild ones, then moderate ones, and finally severe ones.

Most environmental health experts believe that the subtlest detectable effects—those with no outward symptoms, which are not clearly harmful—should be considered "precursors" of more serious effects. By this logic, people who show such subtle changes should be considered at risk for more serious effects if exposure continues.

Skeletal fluorosis, a complicated illness caused by the accumulation of too much fluoride in the bones, has a number of stages. The first two stages are preclinical—that is, the patient feels no symptoms but changes have taken place in the body. In the first preclinical stage, biochemical abnormalities occur in the blood and in bone composition; in the second, histological changes can be observed in the bone in biopsies. Some experts call these changes harmful because they are precursors of more serious conditions. Others say they are harmless.

In the early clinical stage of skeletal fluorosis, symptoms include pains in the bones and joints; sensations of burning, pricking, and tingling in the limbs; muscle weakness; chronic fatigue; and gastrointestinal disorders and reduced appetite. During this phase, changes in the pelvis and spinal column can be detected on x-rays. The bone has both a more prominent and more blurred structure.

In the second clinical stage, pains in the bones become constant and some of the ligaments begin to calcify. Osteoporosis may occur in the long bones, and early symptoms of osteosclerosis (a condition in which the bones become more dense and have abnormal

EPA union's attempt to join lawsuit opposing fluoride standard was rebuffed

In an unprecedented move, the Environmental Protection Agency's union of professional employees, Local 2050 of the National Federation of Federal Employees, attempted to file an amicus curiae brief in a lawsuit against the agency itself in 1986. The lawsuit in the U.S. Court of Appeals for the District of Columbia was initiated by the Natural Resources Defense Council. It charged that the agency had ignored scientific evidence of adverse health effects when it set the recommended maximum contaminant level (RMCL) for fluoride in drinking water at 4 ppm.

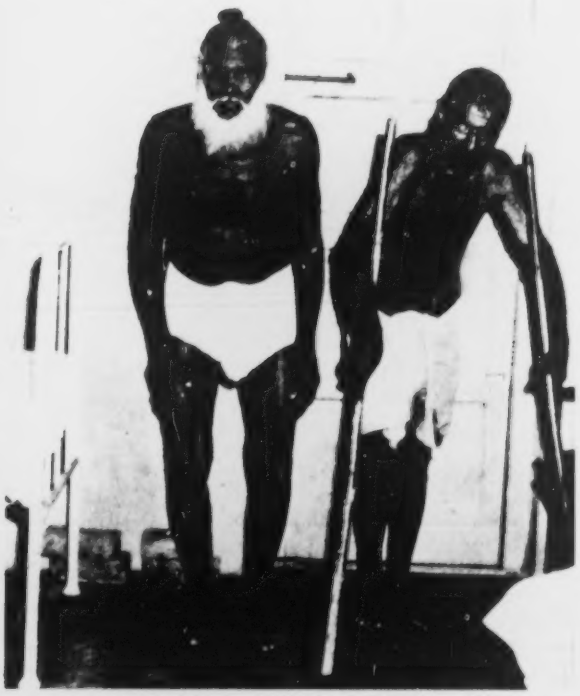
The EPA union, authorized by law to represent 1100 Washington area scientists, lawyers, and engineers, tried to join in the suit because its members believed that the support documents for the RMCL were unprofessional and an embarrassment to the agency. They charged that the fluoride health effects document, which was written by an outside contractor, had been skewed to meet the political goals of requiring very few communities to remove fluoride from their drinking water and avoiding the suggestion that levels of fluoride found in the drinking water of some communities (between 2 and 4 ppm) might cause adverse health effects.

The union's brief cited many studies showing health effects at 4 ppm that had been omitted from the document. In particular, it opposed EPA's labeling moderate to severe dental fluorosis a mere cosmetic effect that therefore did not need to be protected against by the new standard. It also pointed out that some individuals living in areas with 4 ppm natural fluoride in their drinking water would be at risk of developing crippling skeletal fluorosis. Without comment, the court refused to accept the amicus brief from the EPA union.

In 1984, the South Carolina Department of Health & Environmental Control filed suit against EPA to raise or eliminate the fluoride standard. South Carolina objected to the 4-ppm standard because it did not want any community to have to spend the considerable amount of money—as much as $10 per month per household—required to remove fluoride from its drinking water.

Both suits were thrown out of court in February 1987 by a unanimous decision of the three judges, Ruth B. Ginsburg, Robert Bork, and James Buckley. They determined that "EPA reasonably interpreted the statute, responsibly evaluated the sometimes conflicting evidence in an extensive record," and "provided rational explanations for its determination. We therefore uphold EPA's rule as within the bounds of the agency's permissible discretion."

Jaqueline M. Warren, senior staff attorney at the Natural Resources Defense Council, believes the court made the wrong decision. "I don't think EPA should be allowed to set less protective standards in the absence of significant new evidence that would justify that," she says.



These men in India have developed crippling skeletal fluorosis from fluoride in water

crystalline structure) are present. Bony spurs may also appear on the limb bones, especially around the knee, the elbow, and on the surface of tibia and ulna.

In advanced skeletal fluorosis, called crippling skeletal fluorosis, the extremities become weak and moving the joints is difficult. The vertebrae partially fuse together, crippling the patient.

Most experts in skeletal fluorosis agree that ingestion of 20 mg of fluoride a day for 20 years or more can cause crippling skeletal fluorosis. Doses as low as 2 to 5 mg per day can cause the preclinical and earlier clinical stages.

The situation is complicated because the risk of skeletal fluorosis depends on more than the level of fluoride in the water. It also depends on nutritional status, intake of vitamin D and protein, absolute amount of calcium and ratio of calcium to magnesium in drinking water, and other factors.

In parts of India, China, Africa, Japan, and the Middle East, large numbers of people have skeletal fluorosis from drinking naturally fluoridated water. In India about a million people have this disease. Most of the victims live in areas where the water fluoride level is 2 ppm or above, but some cases are found in communities with natural fluoride levels below 1 ppm.

In the U.S., more than a dozen cases of skeletal fluorosis have been reported. Some have occurred at high fluoride levels, others at levels lower than 4 ppm when

Voices of opposition have been suppressed since early days of fluoridation

Ever since the Public Health Service (PHS) endorsed fluoridation in 1950, detractors have charged that PHS and the medical and dental establishment, such as the American Medical Association (AMA) and the American Dental Association (ADA), have suppressed adverse scientific information about its effects.

Some of those who generally support fluoridation make similar charges. For example, Zev Remba, the Washington Bureau editor of *AGD Impact*, the monthly publication of the Academy of General Dentistry, wrote last year that supporters of fluoridation have had an "unwillingness to release any information that would cast fluorides in a negative light," and that organized dentistry has lost "its objectivity—the ability to consider varying viewpoints together with scientific data to reach a sensible conclusion."

The dozen or so scientists C&EN was able to contact who have done research suggesting negative effects from fluoridation agree on this aspect. They all say that fluoridation research is unusual in this respect.

If the lifeblood of science is open debate of evidence, scientific journals are the veins and arteries of the body scientific. Yet journal editors often have refused for political reasons to publish information that raises questions about fluoridation. A letter from Bernard P. Tillis, editor of the *New York State Dental Journal*, written in February 1984 to Geoffrey E. Smith, a dental surgeon from Melbourne, Australia, says: "Your paper ... was read here with interest," but it is not appropriate for publication at this time because "the opposition to fluoridation has become virulent again." The paper poses the question: Are people ingesting increasing amounts of fluoride and can they do so with impunity?

Sohan L. Manocha, now a lawyer, and Harold Warner, professor emeritus of biomedical engineering at Emory University medical school in Atlanta, received a similar letter in 1974 from the editor of AMA's *Archives of Environmental Health*. The editor rejected a report Manocha and Warner submitted on enzyme changes in monkeys who were drinking fluoridated water because of reviewers' comments such as: "I would recommend that this paper not be accepted for publication at this time" because "this is a sensitive subject and any publication in this area is subject to interpretation by antifluoridation groups."

These papers were subsequently published in prestigious British journals, *Science Progress* (*Oxford*) and *Histochemical Journal*. Many other authors have reported similar difficulties publishing original data that suggest adverse effects of fluoridated water.

Most authoritative scientific overviews of fluoridation have omitted negative information about it, even when the oversight is pointed out. Phillipe Grandjean, professor of environmental medicine at Odense University in Denmark, wrote to the Environmental Protection Agency in June 1985 about a World Health Organization study on fluorine and fluorides: "Information which could cast any doubt on the advantage of fluoride supplements was left out by the Task Group. Unless I had been present myself, I would have found it hard to believe."

In his 1973 Ph.D. thesis on the fluoridation controversy, Edward Groth III, a Stanford biology graduate student at that time, concluded that the vast majority of reviews of the literature were designed to promote fluoridation, not to examine evidence objectively. Groth also noted a number of antifluoridation reviews that were equally biased.

According to Robert J. Carton, an environmental scientist at EPA, the scientific assessment of fluoride's health risks written by the agency in 1985 "omits 90% of the literature on mutagenicity, most of which suggests fluoride is a mutagen."

Several scientists in the U.S. and other countries who have done research or written reports questioning the benefits of fluoridation or suggesting possible health risks were discouraged by their employers from publishing their findings. After their paper had been rejected by the editor of *Archives of Environmental Health*, Manocha and Warner were told by the director of their department not to try to publish their findings in any other U.S. journal. NIDR had warned the director that the research results would harm the cause of fluoridation. Eventually, Manocha and Warner were granted permission to publish their work in a foreign journal.

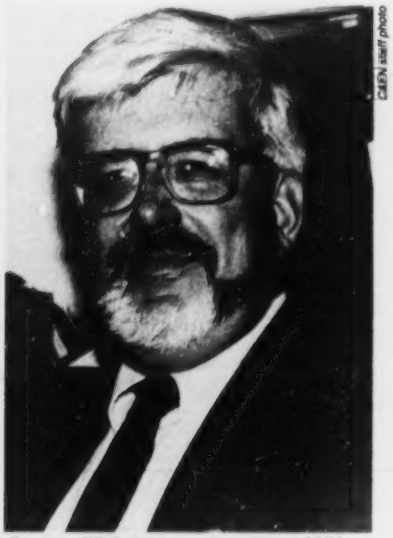
In 1982, John A. Colquhoun, former principal dental officer in the Department of Health in Auckland, New Zealand, was told after writing a report that showed no benefit from fluoridation in New Zealand that the department refused him permission to publish it.

In 1980, Brian Dementi, then toxicologist at the Virginia Department of Health, wrote a comprehensive report on "Fluoride and Drinking Water" that suggested possible health risks from fluoridation. This 36-page study has been purged from the department's library even though it is the only one the department has prepared on the subject. According to current employees, no copy exists anywhere in the department. Spokesmen say the report was thrown

aggravating conditions were present, such as diabetes or impaired kidney function.

In setting the recommended maximum contaminant level for fluoride in drinking water in 1986, EPA considered only crippling skeletal fluorosis as a health effect and established little or no margin of safety, even for this disease. (A margin of safety is a difference between the maximum contaminant level and the level at which health effects first occur in the most susceptible individuals.) According to a Department of Agriculture survey, about 3% of the U.S. population drinks 4 L or more of water per day. Therefore, about 3% of the people who live in areas where the water contains the natural fluoride level of 4 ppm allowed by EPA—such as certain communities in Texas or South Carolina—are ingesting at least 16 mg of fluoride a day, not including the fluoride they derive from other sources, such as toothpaste, food, or air.

Also, because a more or less constant percent of intake is accumulated in bone, persons who consume 8 mg a day for 50 years accumulate about the same



C&EN staff photo

Carton: EPA document omitted 90% of mutagenicity studies

away because it was old but also say the department will be preparing another report on the subject soon.

An ADA white paper written in 1979 states: "Dentists' nonparticipation [in fluoridation promotion] is overt neglect of professional responsibility." An ADA spokesperson says this is still the association's official policy. In recent years, several dentists who have testified on the antifluoridation side have been reprimanded by their state dental officers.

ADA and PHS also have actively discouraged research into the health risks of fluoridation by attacking the work or the character of the investigators. As part of their political campaign, they have over the years collected information on perceived antifluoridation scientists, leaders, and organizations. Newspaper articles about them are stored in files, as are letters about them from various proponents of fluoridation. Little or no effort has been made to verify the accuracy of this information. It is used not only in efforts to counteract arguments of the antifluoridationists, but also to discredit the work and objectivity of U.S. scientists whose research suggests possible health risks from fluoridation.

One example is the false information about the late George L. Waldbott, founder and chief of allergy clinics in four Detroit hospitals, that ADA disseminated widely to discredit the validity of his research. Rather than deal scientifically with his work, ADA mounted a campaign of criticism based largely on a letter from a West German health officer, Heinrich Hornung. The letter made a number of untrue statements, including an allegation that Waldbott obtained his information on patients' reactions to fluoride solely from the use of questionnaires. ADA published Hornung's letter in its journal in 1956 and distributed a news release based on the letter. ADA later published Waldbott's response to this letter. But the widely disseminated original news release was not altered or corrected, and continued to be published in many places. As late as 1985, it was still being quoted. Once political attacks effectively portrayed him as "antifluoridation," Waldbott's work was largely ignored by physicians and scientists.

In November 1962 and 1965, ADA included in its journal long directories of information about antifluoridation scientists, organizations, leaders, and others known to be opposed to fluoridation. Listed in alphabetical order were reputable scientists, convicted felons, food faddists, scientific organizations, and the Ku Klux Klan. Information was given about each, including quotes from newspaper articles, some of which contained false data. The information was published for use by proponents of fluoridation in local fluoridation referenda.

John S. Small, information specialist at the National Institute of Dental Research, is quite willing to talk about the files he keeps on antifluoridation organizations and their leaders. "Of course, we gather information," he says. "These people are running all over the country opposing fluoridation. We have to know what they are up to." Consumer advocate Ralph Nader has a different view of this activity. He calls it an "institutionalized witch-hunt."

It is easy to understand why research on risks of fluoridation has never been more vigorously pursued. Most of the individuals and agencies involved have been promoting fluoridation publicly for nearly 40 years. Research that suggests possible harm threatens them with a loss of face. For example, PHS has historically been the principal source of funds for fluoride research; but ever since June 1950, PHS has been officially committed to and responsible for promoting fluoridation. Thus, the agency has a fundamental conflict of interest.

Colquhoun, now teaching the history of education at the University of Auckland, offers another explanation for what appears to be the suppression of research. He notes that the editorial policy of scientific journals has "generally been to not publish material which overtly opposes the fluoridation paradigm." Scientific journals employ a referee system of peer review. But when the overwhelming majority of experts in an area from which the referees are selected are committed to the shared paradigm of fluoridation, Colquhoun notes, the system lends itself to preservation and continuation of the traditional belief that fluoridation is safe and effective. This results in "single-minded promotion, but poor-quality research, and an apparent inability to flexibly reassess in the presence of unexpected new data," he says.

amount of fluoride in their bones as those who consume 20 mg a day for 20 years. Therefore, for people who drink 2 L or more per day of water with 4 ppm fluoride throughout their lives, there appears to be no margin of safety even for crippling fluorosis. In its regulations for most other drinking water contaminants, EPA has included safety factors of 10 to 100 and has calculated intakes in terms of a lifetime—that is, 70 years instead of 20.

Joseph A. Cotruvo, director of the criteria and standards division of EPA's Office of Drinking Water, says the fact that so few people in the U.S. have actually developed crippling skeletal fluorosis indicates that fluoride levels found in U.S. water are safe and that there is therefore an observed margin of safety. But critics of EPA's standard speculate that there probably have been many more cases of fluorosis—even crippling fluorosis—than the few reported in the literature because most doctors in the U.S. have not studied the disease and do not know how to diagnose it.

Those who ingest much less than 20 mg of fluoride per day may still be at risk of developing less severe

Most of the largest U.S. cities have fluoridated drinking water

City	Population (thousands)	Fluoridation status	Date instituted
New York City	7263	Artificial	1965
Los Angeles	3259	None	
Chicago	3010	Artificial	1956
Houston	1729	Natural/artificial	1982
Philadelphia	1643	Artificial	1954
Detroit	1086	Artificial	1967
San Diego	1015	Discontinued 1954	1952
Dallas	1004	Artificial	1966
San Antonio	914	None	
Phoenix	894	None	
Baltimore	753	Artificial	1952
San Francisco	749	Artificial	1952
Indianapolis	720	Artificial	1951
San Jose	712	None	
Memphis	653	Artificial	1970
Washington, D.C.	626	Artificial	1952
Jacksonville	610	Natural	
Milwaukee	605	Artificial	1953
Boston	574	Artificial	1978
Columbus	566	Artificial	1973
New Orleans	554	Artificial	1974
Cleveland	536	Artificial	1956
Denver	505	Artificial	1954
El Paso	492	Natural	
Seattle	486	Artificial	1969
Nashville-Davidson	474	Artificial	1953
Oklahoma City	443	Artificial	1954
Kansas City (Mo.)	441	Artificial	1981
Fort Worth	430	Artificial	1965
St. Louis	426	Artificial	1955

Sources: Bureau of the Census, National Institute of Dental Research

stages of skeletal fluorosis, such as preclinical forms or the subcrippling clinical stages. In its final report, the Surgeon General's panel said that radiologic changes have been found in bone when fluoride exposure has been about 5 mg per day. Nearly all of those drinking water containing 4 ppm of fluoride and about 3% of the more than 124 million people whose water contains only 1 ppm would have intakes as high as this. It is not known, however, what fraction of those with low-level radiologic changes would suffer joint pains or other clinically obvious adverse health effects. In his landmark study of skeletal fluorosis in cryolite workers in the 1930s, the Danish scientist Kaj Roholm found that some of those with stage I of clinical skeletal fluorosis suffered joint pains and stiffness.

Although skeletal fluorosis has been studied intensely in other countries for more than 40 years, virtually no research has been done in the U.S. to determine how many people are afflicted with the earlier stages of the disease, particularly the preclinical stages. Because some of the clinical symptoms mimic arthritis, the first two clinical phases of skeletal fluorosis could be easily misdiagnosed. Skeletal fluorosis is not even discussed in most medical texts under the effects of fluoride; indeed, a number of texts say the condition is almost nonexistent in the U.S. Even if a doctor is aware of the disease, the early stages are difficult to diagnose.

The possibility that fluoride might cause skeletal abnormalities in children's bones is of particular concern. In its April 1983 draft report, the Surgeon General's committee wrote that moderate and severe dental fluorosis in children may be accompanied by skeletal changes. Although this statement was omitted from the final report in September 1983, the committee did urge more research into the skeletal effects of fluoride, particularly in children. It wrote: "The effects of various levels of fluoride intake on rapidly developing bone in young children are not well understood. Also, the modifying effects of total intake, length of exposure, other nutritional factors, and debilitating illness are not well understood." Since the committee's report was written, PHS and EPA have undertaken no research in this area.

PHS has conducted several studies that it claims show that fluoride levels found in U.S water supplies have had no clearly adverse effects on bones. But the majority of these studies either included a study population too small to detect rare effects or excluded people who would be most likely to suffer from skeletal fluorosis, such as those with kidney disease.

EPA's approach to subtle, preclinical effects of fluoride on the skeleton differs from its usual approach to other environmental agents. For instance, when EPA assessed the health hazards of lead, it made an extraordinary effort to connect the observable effects of low-level exposure (inhibition of certain blood enzymes) with the known adverse effects of slightly higher exposure (decreased synthesis of hemoglobin, anemia, and possible neurotoxic effects). When it set its standard for lead in air, EPA argued that to prevent more serious effects, it needed to limit the more subtle biochemical changes that lead was provoking in millions of children.

By contrast, EPA's assessment of fluoride in water took an almost opposite tack. By defining the most severe known hazard, crippling skeletal fluorosis, as the only effect it was concerned with preventing, EPA dismissed all degrees of fluoride-induced changes in bones less drastic than crippling fluorosis as not being health concerns.

Because fluoride causes denser bones (osteosclerosis), a number of researchers have compared fluoridated and nonfluoridated areas to see if the incidence and severity of osteoporosis is lower in fluoridated areas. A small number of studies in the past 25 years have reported a lower incidence of hip fractures in areas with fluoridated water, compared with nearby areas with low-fluoride water. For example, a recent report, comparing two towns in Finland, prompted widespread media stories that fluoridation is benefi-

cial to the bones of the elderly, as well as to teeth. But a larger number of well-designed studies have found no evidence of a beneficial effect on osteoporosis. However, some of the profluoridation literature states as a fact that fluoridation will help prevent osteoporosis.

Kidney disease

Two areas are of concern in regard to fluoride and kidneys. First, a fairly substantial body of research indicates that people with kidney dysfunction are at increased risk of developing some degree of skeletal fluorosis. Second, a small and inconclusive amount of research suggests that fluoride may actually cause or aggravate kidney disease.

D. Raja Reddy of the Gandhi Medical College in India claims, for example, that "patients suffering from chronic kidney diseases and those with transplanted kidneys do excrete fluoride, though in small quantities, but they are more vulnerable to osteofluorosis and even neurological complications than others." In its final report, the Surgeon General's 1983 committee notes, "As renal function declines, due either to diseases or with aging, plasma and bone fluoride content both increase."

The National Kidney Foundation in its "Position Paper on Fluoridation—1980" also expresses concern about fluoride retention in kidney patients. It cautions doctors "to monitor the fluoride intake of patients with chronic renal impairment," but stops short of recommending the use of fluoride-free drinking water for all patients with kidney disease. It does recommend, however, that dialysis patients use fluoride-free water for their treatments.

Studies show that children with moderately impaired renal function (such as those who have diabetes insipidus), are at some risk of skeletal changes from consumption of fluoridated water, even if the fluoride level is no higher than 1 ppm. A number of researchers have found high concentrations of fluoride in the bones of patients who suffer from kidney disease and have found symptoms of skeletal fluorosis in some of these patients. However, there has been no systematic survey of people with impaired kidney function to determine how many actually suffer a degree of skeletal fluorosis that is clearly detrimental to their health.

Several animal studies suggest that fluoride may have direct adverse effects on the kidneys. For instance, cytological and enzyme changes have been found in the kidneys of squirrel monkeys drinking water with 5 ppm fluoride. It is not known how the changes affect kidney function in monkeys, nor is it known whether humans would suffer similar changes from relatively low levels of fluoride in drinking water. Impaired renal function, however, has been reported to be more common in areas of endemic skeletal fluorosis.

Hypersensitivity

Just as a few people react idiosyncratically to almost anything, some people may have adverse reactions to fluoride whether contained in pills or water. Some individuals seem to be hypersensitive to fluoride pills or drops containing 1 mg or less as well as to fluoride toothpaste. The 1983 edition of the "Physicians Desk Reference" states: "In hypersensitive individuals, fluorides occasionally cause skin eruptions, such as atopic dermatitis, eczema, or urticaria. Gastric distress, headache, and weakness have also been reported. These hypersensitivity reactions usually disappear promptly after discontinuation of the fluoride." (This information was omitted from later editions of the reference.)

Many of those who agree that some people are hypersensitive to fluoride pills, drops, or mouth rinses deny that anyone could be hypersensitive to fluoridated water, even though just as much or more fluoride is contained in an average person's daily intake of such water (the average water intake of 1 to 2 L has 1 to 2 mg of fluoride) as is contained in the standard pills (0.5 to 1 mg).

Some doctors call such hypersensitive reactions allergies. The American Academy of Allergy, however, defines allergies very narrowly—"quantitatively abnormal responses mediated by specific immunologic mechanisms, and therefore by specific antibodies or by certain sensitized cells (lymphocytes)." According to this definition, the academy says, allergies to fluorides do not exist.

Hans Moolenburgh, a Dutch physician who has studied hypersensitive reactions to fluoride, believes the reactions can be explained as effects of a toxic agent rather than as allergies. In large doses, everyone reacts to fluoride. A small fraction of the population, he says, reacts to much lower levels of fluoride.

The late George L. Waldbott, founder and chief of allergy clinics in four Detroit hospitals and noted antifluoridation activist and author, reported treating at least 500 patients who he concluded reacted negatively to fluoridated water. The symptoms included muscular weakness, chronic fatigue, excessive thirst, headaches, skin rashes, joint pains, digestive upsets, tingling in the extremities, and loss of mental acuity. Waldbott used double-blind tests to determine whether fluoride was the cause of symptoms in many of his cases. In each of these patients, the symptoms disappeared when the fluoride was taken away without the patient's knowledge and reappeared when it was given again, but not with the administration of other possible agents.

Chemicals used to fluoridate water are by-products of fertilizer production

	Consumption for fluoridation, tons per year	Size of community served	How made
Hydrofluosilicic acid	80,000	All sizes	By-product of phosphate fertilizer manufacture
Sodium silicofluoride	60,000	Medium and large	Neutralizing hydrofluosilicic acid with sodium carbonate
Sodium fluoride	3,000	Small	Neutralizing hydrofluosilicic acid with sodium hydroxide

Other investigators have reported similar cases. Reuben Feltman and George Kosel, then researchers at Passaic General Hospital in New Jersey, found that 1% of their subjects, who were children and pregnant women, reacted adversely to daily pills containing 1.0 to 1.2 mg of fluoride. The reactions, which affected the skin and gastrointestinal and nervous systems, disappeared when the fluoride was discontinued without the patients' knowledge.

Moolenburgh, G. W. Grimbergen, and a number of other Dutch doctors performed double-blind experiments on patients who became ill after fluoridation began in the Netherlands. By using coded bottles of drinking water, some fluoridated and some not, the physicians showed that the symptoms were caused by fluoride, rather than some other factor.

Moreover, a report by the British Royal College of Physicians states that some patients receiving 9 mg of fluoride per day for osteoporosis suffered adverse side effects. This is about the same intake some would have in areas where the water fluoride level is 2 ppm.

Because the number of studies has been small, it is not known with certainty what fraction of the population may be hypersensitive to fluoride. Since all of the reported symptoms can be caused by other factors, reactions to fluoride could go undiagnosed unless a physician was looking specifically for fluoride sensitivity.

Enzyme and mutagenic effects

Sodium fluoride is used in many in-vitro studies to block the action of enzymes, in part because it can interfere with so many different enzymes.

One way the fluoride ion serves as an enzyme inhibitor in the lab is by acting on the GTP-binding proteins (or G-proteins). Fluoride ion also may disrupt enzymes by forming strong hydrogen bonds with amides. Fluoride switches off an enzyme by attacking its weakest links—the delicately balanced network of hydrogen bonds surrounding the active site. In some enzymes, the fluoride ion attaches itself to the atom at the heart of the enzyme and then disrupts the active site by attracting groups that can form strong hydrogen bonds to itself. Eventually, this inactivates the enzyme by changing its molecular conformation.

Because enzymes mediate most of the biochemical processes essential to life, any environmental agent that can affect a wide range of enzymes could, at least in theory, have a wide variety of effects on an organism's health. For that reason alone, potential effects of fluoride on enzymes are of great interest. In addition, as has been discussed earlier, effects on enzymes are often the first detectable biological changes produced in an organism exposed to a toxic agent, just as enzyme changes in the heme biosynthetic pathway precede the onset of lead-induced anemia. Detailed knowledge of fluoride's effects on a number of human enzymes could lead to an array of sensitive tests for the earliest signs of possible harm from excessive intake of this element and more precise identification of individuals who are at risk.

Studies on enzyme preparations in test tubes, however, don't necessarily predict what will happen in living humans. In at least 11 in-vivo animal studies, fluoride has been shown to influence enzyme activity. In some tests, enzyme activity was depressed; in others, it was stimulated. In addition, one study indicates a transient decrease in human serum enzyme activity associated with the advent of water fluoridation. But there have been few other studies to measure the effects of typical levels of fluoride intake on enzyme activity in people.

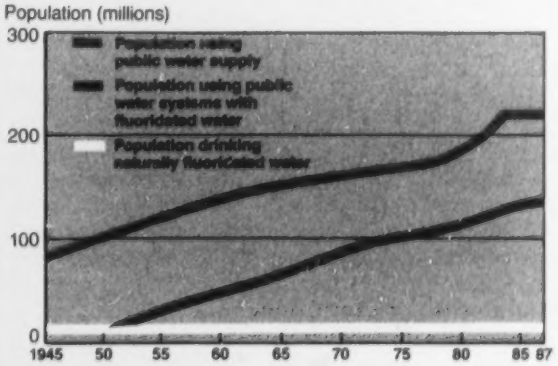
Some scientists believe that interference with enzyme activity is the major mechanism by which fluoride exerts physiological effects. Certain changes in enzyme activity can be minor, easily repaired by the body. But others could be the first signs of more serious alterations that would take place with continued exposure to fluoride.

Just as the fluoride ion may disrupt enzymes with its ability to form strong hydrogen bonds, it may also disrupt DNA by interfering with its hydrogen bonding. The evidence for this mechanism consists of theoretical calculations, however, and some scientists, such as George R. Martin, chief of the laboratory of developmental biology and anomalies at NIDR, do not find it at all convincing.

A great many lab tests have been performed to measure the possible mutagenicity of the fluoride ion. The results are contradictory and often very confusing. Some of the positive mutagenicity tests involve very high concentrations of fluoride ion, so high that they would not be found anywhere in the human body. Others involve levels comparable to those in drinking water. However, the important consideration is not fluoride levels found in drinking water, but levels found in the human body. Geoffrey E. Smith, dental surgeon from Melbourne, Australia, says that when bones lose fluoride, localized high concentrations may result.

For example, in 1982, Aly H. Mohamed and Mary E. Chandler of the University of Missouri in Kansas City reported that 1 to 200 ppm fluoride in drinking water induced changes in a dose-dependent manner in bone

Population drinking artificially fluoridated water has grown steadily since 1950

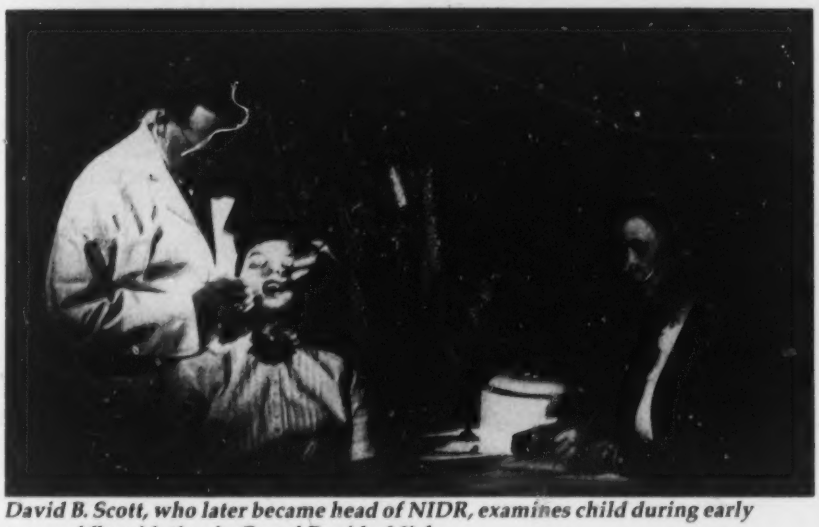


Source: National Institute of Dental Research

marrow cell chromosomes and spermatocytes of living mice. In 1978, Danuta Jachimczak of the Pomeranian Medical Academy in Szezecin, Poland, showed that fluoride levels as low as 1 ppm caused changes in the chromosomes of human leucocytes in vitro.

Even if all the mutagenicity tests were positive, this would not prove fluoride is a mutagen in humans. But scientists consider a chemical a more likely mutagen if several types of lab tests are positive.

John R. Bucher of the National Institute of Environmental Health Sciences says that tests in his lab show sodium fluoride mutagenic for cultured lymphoma cells derived from mice. He notes that a number of similar studies have been published by other investigators. Because most carcinogens are also mutagens, evidence of mutagenicity also bears on the issue of fluoride's potential for carcinogenicity. Bucher's results do not prove sodium fluoride is a carcinogen, but do "point out the need to test the chemical in the two-year rodent bioassay, which we are doing," he explains.



David B. Scott, who later became head of NIDR, examines child during early years of fluoridation in Grand Rapids, Mich.

Because he believes that epidemiological studies show that fluoride has no effect on birth defects and cancer, Martin says he is not concerned about the positive mutagenicity studies. John S. Small, information specialist at NIDR who has a similar view of the epidemiology studies, calls the mutagenicity question a "used-up issue."

Very little work has been done on fluoride's potential mutagenicity in humans. In one study involving only six patients receiving fluoride treatment for osteoporosis, inhibition of DNA repair was observed in one patient. But no firm conclusions can be drawn from such limited research, and more intensive research simply has not been pursued.

Birth defects

If the fluoride ion is a mutagen, it may be capable of causing birth defects in humans. Few studies have been done in this area. During the 1950s, Ionel Rapaport, a researcher at the Psychiatric Institute of the University of Wisconsin who specialized in the epidemiology of mental disorders, found that babies born in areas of North Dakota, South Dakota, Illinois, and Wisconsin with natural fluoride in drinking water had twice the incidence of Down's syndrome as those born in fluoride-free areas. However, a few more recent surveys have shown a smaller or no relation between water fluoridation and Down's syndrome.

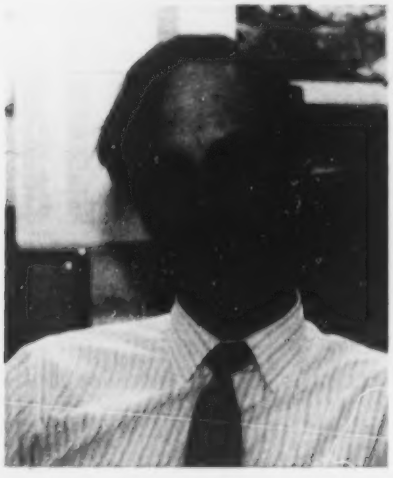
In 1976, J. David Erickson, an epidemiologist at the Centers for Disease Control, looked at the rates of overall birth defects in the fluoridated and unfluoridated counties around Atlanta and also at national birth defect data supplied by the National Cleft Lip & Palate Intelligence Service (NCLPIS). Like Rapaport, he recorded a higher rate of Down's syndrome births among younger mothers in the fluoridated areas around Atlanta, but he found no substantial overall differences in the birth defect rates that form a consistent pattern for the metropolitan Atlanta and the NCLPIS data. However, many of the mothers in the Atlanta area counties had been exposed to fluoridation for only a few years and the NCLPIS data indicated substantial underreporting of birth defects. Clearly, there is need for more work in this area.

Cancer

Two types of research have been done to determine if fluoride causes cancer—lab studies of animals and human epidemiology studies. Neither kind of research has shown clearly that fluoride is a carcinogen in animals or humans. But the studies have not been extensive enough to show that it clearly is not a carcinogen.

A few animal bioassays on fluoride in the 1950s produced contradictory and inconclusive evidence on the ion's potential to cause or accelerate cancer. In 1977, Congress requested that the National Institutes of Health conduct large-scale animal tests of fluoride for carcinogenicity. In the first chronic test, certain rats in both the control and dosed groups became ill and died at an early age, probably because their feed, highly purified to remove fluoride, was deficient in certain essential trace elements. The study on 360 mice and rats was done over again with a different feed. Results are scheduled to be available in 1990. Because of its well-established effects on many enzymes in vitro, Groth suggests that fluoride also should probably be tested for cocarcinogenicity (ability to act as a promoter of cancer) in animals. But no such research is now under way.

Reprints of this C&EN special report will be available in black and white at $5.00 per copy. For 10 or more copies, $3.00 per copy. Send requests to: Distribution, Room 210, American Chemical Society, 1155—16th St., N.W., Washington, D.C. 20036. On orders of $20 or less, please send check or money order with request.



C&EN staff photo

Groth: science cannot say how much uncertainty we should tolerate

Cancer epidemiology studies are probably the most controversial issue in the fluoride debate. In the 1950s, PHS did some general mortality studies of crude overall death rates from all causes. It found no excess mortality from cancer or other causes in naturally fluoridated areas, compared with areas without fluoride in water.

In 1977, biochemist John Yiamouyiannis, president of the Safe Water Foundation (a citizens group opposed to fluoridation), and Dean Burk, retired after working for 35 years as a biochemist at the National Cancer Institute, published a study comparing cancer mortality rates from the 10 largest U.S. cities with fluoridated water with mortality rates from 10 of the largest cities with nonfluoridated water. Before 1952, when fluoridation had not yet begun in most of these cities, the cancer death rates rose together. After 1952, the death rates for people over 45 in the cities with nonfluoridated water were 4 to 5% lower than those for the cities with fluoridated water. In England, Sir Richard Doll and Leo Kinlen of Oxford University and Peter D. Oldham and D. John Newell of the Royal Statistical Society at about the same time completed studies that show no excess of cancer mortality in those same cities in the U.S. with fluoridated water.

The National Research Council (NRC) reviewed this discrepancy in 1977 and concluded that the conflicting results could be explained in large part by the different data sets and different analytical approaches used by the investigators. According to the NRC analysis, the margin of possible error in the most sensitive cancer study is about three cancer deaths per 100,000 people or 4000 possible excess or fewer cancer deaths per year among the 130 million individuals drinking fluoridated water in the U.S.

A June article in the *Proceedings of the Pennsylvania Academy of Science* by attorney John R. Graham, Burk, and Pierre J. Morin, former scientific adviser for the minister of environment in Quebec, also reviews this controversy. It concludes that, compared with the unfluoridated cities, there is an excess of 20 to 30 cancer deaths per 100,000 people who live in the major fluoridated cities of the U.S. for at least 15 to 20 years.

Several investigators have looked for a more specific relationship between stomach cancer and fluoridation. The hypothesis is that fluoride would be more likely to cause stomach cancer than any other type because fluoride in the stomach forms hydrofluoric acid, a powerful irritant that is mutagenic in several in-vitro lab tests. In 1978, CDC's Erickson, after correcting for age, race, and sex, found the death rate from cancer of the digestive system was 9% higher in cities with fluoridated water. However, when he subtracted all subjects with Asian and Hispanic surnames and corrected for education and population density, the excess disappeared.

The Knox report, a comprehensive review of most fluoride cancer studies that was completed in 1985 by the Royal College of Physicians in England, concludes that there is no convincing evidence that cancer death rates are higher in areas with fluoridated water. Thus, as with most environmental agents that have been studied for their effects on cancer, the results for fluoride are still inconclusive.

Values influence the choice

Even if all evidence from fluoride research indicated that the risks are slight, not everyone would agree that it is proper to fluoridate water supplies. Obviously, there is never enough time or money to investigate all the scientific questions, and some research results will always be equivocal. And, at least in environmental health, it is, of course, impossible for science to establish anything with absolute certainty.

The decision to fluoridate a community's water or not boils down to a matter of values. Scientific evidence can make the choice more clearcut, more rational, but the choice can't be made purely on the basis of scientific evidence. So long as there is uncertainty about risk from fluoridation, some people will not want to accept that risk. And others who favor fluoridation will demand proof of harm beyond a reasonable doubt before they reject it. According to Groth, "A scientific assessment cannot say what degree of adverse effects is acceptable in return for the expected benefits. ... It cannot say how much uncertainty we should tolerate in estimates of hazards when more than 100 million people are exposed to lifelong ingestion of fluoridated water. Those decisions are value judgments, and scientists' values are no better than everyone else's."

If the risks could be shown to be minuscule beyond a reasonable doubt, it still might make no sense to fluoridate water supplies if the benefits are also small. Perhaps the best approach is, as Groth suggests, not to make the issue whether to fluoridate public water supplies or not. Such an approach allows for no compromise: A water supply is either fluoridated or it is not. Perhaps a better question for policy makers, scientists, and citizens to address is: "What is the best way to promote dental health?" he says. Fluoridation might well be part of the answer, Groth suggests, but communities should simultaneously examine the pros and cons of a variety of other approaches, too. That way, the characteristic all-or-nothing, fight-to-the-finish political battle over fluoridation might some day truly become a historical curiosity. □